Essentials of Ethnobotany on Millets

～Their Origin and Dispersal around Indian Subcontinent

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Preface

During the most time of my life, I had researched the object on the domestication process and dispersal roots of grain crops, especially millets, Gramineae. The objectives which I research the plants in Quaternary, are the four objectives as follows. The first is understanding how our human being have expanded the relationship between them and the plants in their evolution process. The second is considering the historical process on constructing agricultural civilization, from the steps of pre-farming using fire, farming/ horticulture, via one of wild animals. The third is considering the future agricultural technology applied bio-science, information technology comparing the present agriculture. The fourth is integrating basic botany, subsistence, agriculture as ethnobotany of millets. Furthermore, I have recognized that the stage of domestication process exists from wetland, via paddy field, and then upland field in Asia, writing this manuscript now.

Why do we study millets as orphan crops today? These are also called neglected and underutilized species. However, Dr. Swaminathan (2022) questioned again whether the naming is a correct view. Indian people had celebrated the special year of millets in 2018. Indian Government had proposed the International Year of Millets to Food and Agriculture Organization. The year was scheduled for 2026. However, it was changed to 2023, because the United Nation had been decided that the period was held during UN Decade of Action on Nutrition (2016~2025), UN Decade of Family Farming (2019~2028) and additionally UN Declaration on the Peasants (2018).

Nowadays, not only millets but also various landraces of domesticated plants were disappeared. People has forgotten the traditional knowledge system on subsistence and then lost their biocultural diversity. I will propose that we transit to the civilization for all organisms, in order to evaluate again and continue these basic culture complex including the subsistence created in Jomon period, upland farming and paddy field in Japan,

In the present Anthropocene, Quaternary, the population of human being is over 8 billion, and then our food sovereignty/security are urgent issue under the climate change. Because the yields of major grains have reached to the upper limit, we must avoid the crisis consequently by growing various grains and ensure the total yield of grains.

My graduation thesis (1972) was “Anther culture of Triticeae,” master’s thesis (1974) was “Tillering of *Zea mays*,” and Docter’s thesis (1980) was “Evolution from perennials to annuals in weeds.” I have proceeded field survey of millets in parallel. I have visited many farmers in Kanto Mountain area. Therefore, my research methods have started from physiology, ecological genetics to multivariate analysis of morphological characteristics on the farm field and greenhouse, to quantitative analysis of their biological components.

Moreover, I had visited many farmers and fields in all Japan, Indian subcontinent, Central Asia and so on in order to get local seeds of grains, their information about cultivating, processing, and cooking methods, then analysis statistically. I tried namely to integrate all research data which was ethnology, cultural anthropology, archeology, linguistics based on botany of weeds, millets including rice, wheat, legumes, and tubers. For this research project, I had supported by many researchers, but I did all research action by myself until my retirement.

I have written five books self-selected more 10 years after my retirement. I used my research data collected for over 50 years, integrated them, and then considered the domestication process and

dispersal routs. This is a methodology from scientific analysis to integrated environmental studies. In this integrated methodology, I have been able to understand gradually from gathering wild grains, pre-farming, semi-domestication, to domestication process (botanical origin) and dispersal route (geographical resource). Moreover, I keep in mind that I have progressed the ethnobotany to the integrated domain including the origins of agriculture and city states, ethnic food culture, comparison among agricultural words. However, there is a limit, because the research technology has been progressed and many papers are published.

This special issue is composed of studies on the agricultural complex, domestication process, and dispersal of millets, especially *Setaria pumila* (syn. *Setaria glauca*) and *Panicum miliaceum* and not major crops such as rice, wheat, barely, and maize, in the Indian subcontinent. *Setaria pumila* has been dispersed in only a very limited area of the Deccan Plateau (Kimata 2015a, 2015b), while *Panicum miliaceum* has been dispersed throughout Eurasia (Kimata 2015d), including the Indian subcontinent, and recently North America and Australia. It is very fascinating from an environmental perspective of history and geography that the distribution patterns of *Setaria pumila* and *Panicum miliaceum* are remarkably different.

Only 50 years in my researcher life, I have met so many masters and friends. As the result, I have been able to expand my research contents. Also, I have seen many beautiful nature and kind people. As a botanist, I am very happy around beautiful flowers in my life.

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Moreover, we had many expeditions conducted by Kyoto University, Tokyo Women's University and Tokyo Gakugei University supported by Japanese and Indian Governments in the Indian subcontinent from 1983 to 2001.The author would like to thank cordially Indian farmers for kind giving local varieties of millets; Prof. S. Sakamoto and Dr. Y. Ishikawa, Kyoto University; the late Professor H. Kobayashi, for his excellent advice and warm collaboration during the field survey in Indian Subcontinent during in 1985, 1987 and 1989; Dr. Y. Suyama, Tohoku University; Prof. I. Fukuda, Tokyo Women's University, Dr. L. Kanhasuan, Phranakhon Rajabhat University, Thailand for their kind advice. Especially, I wish to express my deepest gratitude to Dr. Sadao Sakamoto, Professor Emeritus of Kyoto University, for his many valuable suggestions in the planning of the studies again. I should be thankful for what my dearest friend Mrs. Tamiko Kimata and our family encouraged me in my hobby research.

Contents

Chapter 1　Ethnobotany and the Research Methods

Grain crops in the World

The seeds of Gramineae grain crops are mostly non-toxic with a few exceptions, nutrient-rich and live long. Their many wild grains had been used to eat until today, for example, *Dactyloctenium aegypticum* (annual) grown in the savanna area, Africa, wild rice, *Oryza rufipogon* (perennial) in east/south India, wild rice, *Zizania aquatica* (annual) in Great Lakes, north America and so on. The domesticated grain crops are shown in Table 1. You are astonished by various species, but several species have disappeared, and the other hand same species have been under domesticating process. I will a new model on the domestication process and disperse routes in chapter 5, after I have discussed the forerunners' hypotheses (de Candolle 1886, Vavilov 1926, Nakao 1967, Sakamoto 1988, Graeber and Wengrow 2021).

The grain crops domesticated in Africa are mostly annual C_4 plants. Triticeae domesticated in South-west Asia are annual C_3 plants. Also, the grain crops domesticated from Central Asia, India to East Asia are mostly annual C_4 plants. However, same species including rice are perennial plants and are grown as ecological annuals. These are changed from perennial to ecological annual by artificial selection during domestication process. The growth habit of annual was very important characteristics under the domestication process.

Millet is the collective term to the grain crops without major grains such as bread wheat, rice and maize. The total yield of grain crops was 3.9 billion tones including maize (37.7%), rice (25.3%) and bread wheat (23.3%) by the data of FAOSTAT 2022. The yield of millets was 0.5 billion (13.7%).

The remarkable characteristics of millet are numerous small seeds (caryopsis) attached a big panicle, mainly summer annuals which had been domesticated in savanna area conditioned under the tropical/sub-tropical zones, or in monsoon area under the temperate zone (Sakamoto 1988). These plants had been adapted under the climate change involving crustal deformation in the Quaternary. They are maintaining the local adaptability by higher genetical variability and plasticity through crossing with their relative weeds. Because most millets are C_4 plants which have higher photosynthetic ability, their yield are so much under the climatic condition in the semi-arid and mountainous condition.

The biomass of all plant in Millets have high. Namely, human being eats the seed grains, while animals eat their stems and leaves. Millets are very useful crop for small farmers conducting animal husbandry. It is true that millets are main food everywhere under the severe condition in Afro—Eurasia. Moreover, the demand of millets is promoting today, because they are healthy and functional foods for many urban citizens.

The concept of millet is confused commercially in Japan.　I use the name "millet," as a narrow

sense as shown in Table 2. I do not use a wide definition as commercial words in this book.

Table 1. Domesticated grains in the world.

Scientific name	English name	Indiann name	Chromosome number	Grawth habit	Photosynthesis	Ancester	Geographical origin
Africa							
Sorghum bicolor Moench	sorghum	jowar	2n=20 (2x)	annual	C4	*S. bicolor* var. *verticillifolrum*	Africa
Pennisetum americanum (L) Leeke	pearl millet	bajira	2n=14 (2x)	annual	C4	*P. violaceum*	Africa
Eleusinne coracana Gaertn.	finger millet	ragi	2n=36 (4x)	annual	C4	*E. coracana* var. *africana*	East Africa
Eragrostis abyssinica Schr.	tef		2n=40 (4x)	annual	C4	*E. pilosa*	Ethiopia
Digitaria exilis (Kippist) Stapf.	fonio		2n=54 (4x)	annual	C4	wild	West Africa
Digitaria iburua Stapf.	black fonio			annual	C4	wild	West Africa
Brachiaria deflexa (Schumach) C. E. Hubbard	animal fonio			annual	C4	wild	West Africa
Oryza glaberrima Steud.	African rice		2n=24 (2x)	annual		*O. barthii*	West Africa
Europe from India							
Digitaria sanguinalis (L.) Scop.	mana grass			annual	C4		Europe from India
Phalaris canariensis L.	canary seed			annual			South Europe
Asia							
1. South west Asia							
Avena sativa L.	oat		2n=42 (6x)	annual	C3		South west Asia
Avena strigosa Schreb.			2n=14 (2x)	annual	C3		South west Asia
Avena abyssinica Hochst.			2n=28 (4x)	annual	C3		South west Asia
Avena byzantina C. Koch.			2n=42 (6x)	annual	C3		South west Asia
Hordeum vulgare L.	barley	jao	2n=14 (2x)	annual	C3	*H. vulgare* ssp. *spontaneum*	South west Asia
Triticum monococcum L.	small spelt		2n=14 (2x)	annual	C3	*T. monococcum* ssp. *boeoticum*	South west Asia
Triticum trugidum L.		aja	2n=28(4x)	annual	C3	*T.trugidum ssp. dicocoides* + *Aegilops speltoides*	South west Asia
Triticum aestivum L.	bread wheat	gehun	2n=42 (6x)	annual	C3	*T.trugidum* + *A. squarrosa*	South west Asia
Triticum timopheevi Zhuk.			2n=28 (2x)	annual	C3	*Triticum timopheevi* ssp. *araraticum*	South west Asia
Triticum zhukovskyi Menbde & Ericzjan			2n=42 (6x)	annual	C3		West Goergia
Seale cereale L.	rye		2n=14 (2x)	annual	C3	*S. montanum*	South west Asia
2. Central Asia							
Setaria italica (L.) P. Beauv.	foxtail millat	thenai	2n=18 (2x)	annual	C4	*S. italica* ssp. *viridis*	Central Asia/South Tianshan
Panicum miliaceum L.	common millet	cheena	2n=36 (4x), 40, 49, 54 (6x), 72 (8x)	annual	C4	*P. miliaceum* ssp. *ruderale*	Central Asia/South Tianshan
3. India							
Panicum sumatrense Roth	little millet	samai	2n=36 (4x)	annual	C4	*P. sumatrense* ssp. *psilopodium*	India/Decan Plato
Paspalum scrobiculatum L.	kodo millet	kodora	2n=40 (4x)	perennial	C4	wild	India/Decan Plato
Echinochloa flumentacea Link.	sawa millet	jangora	2n=54 (6x)	annual	C4	*E. colonum*	India/Decan Plato
Brachiaria ramosa (L.) Stapf.	browntop millet	korne		annual	C4	wild	Inndia/East Garts
Setaria pumila (Poir.) Roem. & Schult.	yellow foxtail mil	kolati	2n=18 (2x), 36 (4x), 72 (8x)	annual	C4	wild	India/Decan Plato
Digitaria crusiata (Nees) A. Caus	Khasi millet	raishan		annual	C4	wild	India/ Khashi Hill
4. South east Asia							
Coix lacryma-jobi var. *ma-yuen* (Roman.) Stapf.	Job's tears	gurya	2n=20 (2x)	perennial	C4	*Coix lacryma-jobi* var. *lacryma-jobi*	Zomia
5.China							
Oryza sativa L.	rice	dhan	2n=24 (2x)	perennial	C3	*O. rufipogon* L.	China/ Pearl river
Echnochloa oryzicola Vasing.			2n=36 (4x)	annual	C4	wild	China/ Yunnan
Podiopogon formosanus Rendl				perennial		wild	Formosa
Fagopyrum esculentum Moench	buckwheat		2n=16 (2x)	annual	C3	*F. esculentum* ssp. *ancestrale*	South west China/Yunnan
Fagopyrum tartaricum (L.) Gaertn.	Tartary buckwheat		2n=16 (2x)	annual	C3	*F. tartaricum* ssp. *potanini*	South west China/Tibet
6.Japan							
Echinochloa utilis Ohwi et Yabuno			2n=54(6x)	annual	C4	*E. crus-galli*	North Japan
America							
Zea maays L.	maize	makai	2n=20 (2x)	annual	C4	*Z. mays* ssp. *mexicana*	Meso America
Panicum sonorum Beal.	saui			annual	C4	*P. hirticaule*	Mexico
Zizania aquatica L.	wild rice		2n=30	annual		wild	North America, Canada
Bromus mango E. Desv.				annual/perennial		wild	South Chile, South Argentina
Amaranthus hypocondriacus L.			2n=32, 34 (2x)	annual	C4	*A. cruentus* (*A. hybridus*)	Andes
Amaranthus acaudatus L.			2n=32, 34 (2x)	annual	C4	*A. cruentus* (*A. hybridus*)	Andes
Chenopodium quinoa Willd.			2n=36 (4x)	annual	C4	*C. quinoa* ssp. *miilleanum*	Andes

Table 2. Terminology of millets

name	explanation
strict definition	Millet is the collective term to the grain crops without major grains such as bread wheat, rice and maize.
	numerous small seeds (caryopsis) attached a big panicle, mainly summer annuals which had been domesticated in savanna area conditioned under the tropical/sub-tropical zones, or in monsoon area under the temperate zone
small millets	foxtail millet, common millet, finger millet, and so on.
	except large seed millets, i.e., sorghum, pearl millet and Yob's tears.
wide definition	millets and pseudocereals including *Fagopylum* ssp., *Amaranthus* ssp,, and *Chenopodeum* sp.
loosely difinition	the grain crops without major grains such as bread wheat, rice and maize. Recently, comarcial name adding barley, rye, oats, or reddish/purple rice, sesame, perilla, mung bean etc.

Research Methods and Materials

Botany

In the research methodology on plant domestication, de Candolle (1883) had indicated that botany was most important domain and more needed the different domains, for example, archeology, linguistics, etc. He had described each crop in detail, in addition, he pointed out that annuals were very useful. The important domesticated plants were mostly belonged to Gramineae, Fabaceae and Brassicaceae. We must explore the wild species in order to make the geographical origin clear. Botany was a valuable research method for clarifying the botanical origin of domesticated plant. Because ancient people were able to grow annuals species easy, annuals plants had very important role for people. Farming had begun very slowly for long term.

Vavilov (1926) had researched the botanical origins and geographical resources of domesticated plants by the differential phytogeographic method. Kihara (1954) had conducted the genome analysis on Triticeae and had elucidated the botanical origin of bread wheat. Nakao (1967) had proposed the botanical origin and their geographical resources with his wide conceptual ability, having a regard for de Candolle' methodology. Moreover, he had expanded the theory such as "Evergreen broad-leaved forest culture," together with Ueyama and Sasaki.

Sakamoto (1988) had changed his research interest from the phylogenetic of Triticeae to the domestication of millets, since he had been inspired by eating injera in Ethiopia. I have become his student about 1970. Then I have studied on the agricultural complex of millets all in Japan and Indian subcontinent.

Modern Ethnobotany

Cotton (1996) had written that the ethnobotany constituted a diverse field of study which examined all aspects of the reciprocal relationships between plants and traditional peoples. It is, by necessity, multidisciplinary in its approach and draws from a broad range of subject area, e.g., ethnoecology, traditional agriculture, cognitive ethnobotany, material culture, traditional phytochemistry and paleoethnobotany. Their applied areas are economic botany including agriculture, crafts, pharmaceutical, and ecology including flora management, biodiversity, human ecology. In addition, the ethnobotany is indicated need of environmental lows, the principle of learning environment and practices to us. Their research methods are applied cultural anthropology,

ethnology and botany.

I have respected strongly Nakao's achievement, the basic agricultural complex (1966, 1967), therefore, I have used it the most important concept to research millet and learning environment. However, I have never been affected his hypothesis, "Evergreen broad-leaved forest culture," and also Yanakita's concept "Rice-growing single ethnic group theory," which were taken the world by storm. Dr. Sakamoto had suggested me strongly that you never considered your paper under the influence from the other famous hypothesis, when I had written my first paper to Anthropological magazine. Therefore, I had decided that I never followed famous authoritative hypothesis and fashionable theory. I kept in mind using the data and results gotten by myself.

Because ethnobotany has natural scientific method, it is very important the stories heard directly from farmers and the observation on their field. Also, our experiences in the nature and social environment of villages are valuable. I had conducted the cultivation tests, biological experiments and observation using seeds, herbarium specimen and so on. I will consider the new model of domestication process and dispersal routs in this book.

Archaeology and history in Holocene, Quaternary

The studies on domestication process and dispersals are conducted not only in geographic space, but also historical times. Therefore, we must make use of their background materials. I have not directly examined and analyzed fossils, remains, etc., in the historical sites. I have visited many museums and historical heritages. I have read archeological books, and directly visited many archeologists in Japan and United Kingdom.

Resources of processing/cooking methods

The millets had rarely been excavated from archaeological sites. Their ancient documents were very few. Therefore, we need the field research data of millets on ethnology and cultural anthropology in order to solve the domestication and dispersal routs of millets. The dispersal of millets nearly always is followed by a basic agricultural complex (Nakao 1966, 1967), that is to say, "from Seeds to Stomach" such as the methods of growing, processing, cooking, food culture and agricultural rites. We consider the origin and dispersal of grain crops comparing with those cultural history. For example, the variety with glutenous starch of seeds had been dispersed in mostly east Asia including Japan, but they had never dispersed toward the west. Those varieties had not dispersed and disappeared on the way to India, because the west side people did not like the taste.

Bread is a processing food made from the flour of bread wheat, which has been dispersed from Middle East to the east and west. Boiled rice had been dispersed from China to the west. Pilaf made of rice had been dispersed from Central Asia to the west and south. Maze had introduced from America to Europe after 15th century. Today maize is used traditional cooking such as polenta in Italy or ugari in Africa. People substitutes a new ingredient for common millet or foxtail millet. We need carefully consider the processing and cooking in order to clear old/new.

The victor group had high yield grain, for example, bread wheat against einkorn wheat and emmer wheat. When they became the ruler, they discriminated traditional crops which an indigenous loser had eaten. However, those neglected crops have been continued to grow by the loser/escape group for live and free under the harsh and poor condition (Scott 2017). Because the indigenous

people have continued their daily life, they need use traditional crops for several millennial years. As Johonson (1992) had said that both crops are important. Three major crops of the winner, bread wheat, rice and maize, were the tax and commodities, while the other crops (including millets) of survivors/indigenous people, were important food for survival.

Comparative study on the vernacular names of millets and processing/cooking in Linguistics

Of course, I had tried to learn local languages, but we used English as a common language, because each local people had used so many languages. Nevertheless, we had needed doble and/or triple translations among English and local languages.

We had heard the methods on cultivation, processing and cooking, and also the local farmers had shown us their methods. They had written the vernacular names of crops and foods in English characters for us. Moreover, I had confirmed the names by the restaurant menus and cook books.

After Bellwood and Renfrew (2002) had proposed "language/farming hypothesis," many researchers had promoted the research method integrated among linguistics, archaeology, genetics, etc. Moreover, in order to reconsider, I have referred to the linguistic analysis by Ohno (2000, 2004) and Southworth (2005).

Now, I must give readers a heads-up on the two concepts. One is the terminological difference, using in 'origin' of plant domesticated from ancestral species under the relationship between human beings and plant, and using in 'resource' of farming around a geographical area (Tanaka 1975). The beginning of farming had been very slowly promoted as cultural phenomena. After several millennia, city states had established and also synchronically an agriculture had been stated by the helots. Another one is the terminological difference between 'farming' (subsistence) and 'agriculture' (industry). Therefore, it had been called 'Agricultural Revolution.' We do not consider 'Farming Revolution.'

Field researches at mountainous villages in Cultural anthropology

We had conducted many field researches on cultural anthropology in addition the botanical basic experiments. Today also, traditional farmers and people cultivate many kinds of millet on the farming fields in the foothills and valley of mountainous/hilly regions. We had visited directory to hundreds of farmers, and had heard the information on their methods of cultivation on the farm, processing and cooking in the kitchen. Furthermore, the farmers had given us many seeds of local millet varieties for the research and conservation.

We had visited all Japan from Okinawa to Hokkaido, mainly the Indian subcontinent, Central Eurasia, and so on. We had observed wide areas by car with corporation of regional agricultural stations, National Bureau of Plant Genetic Resources, Indian Council of Agricultural Research, All India Millet Improvement Project, and Pakistan Agricultural Research Council, Plant Genetic Resources Laboratory, National Agriculture Research Center. We did not stay at the particular village as typical anthropologists.

I had participated six times in expeditions for millet research and collected numerous accessions of millets and their relative species, with information on their agricultural complex, from hundreds of farmers in their villages and fields (Table 3). I mainly visited the southern foot of the Himalayas and Western and Eastern Ghats in and around the Indian subcontinent between 1983 and

2001. The research team used many means of transportation, such as car, train, airplane, and their feet, for frequent field trips (Figure 1). Particularly, the trips extended widely over Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Telangana, Maharashtra, Madhya Pradesh, Orissa, Chhattisgarh, Jharkhand, West Bengal, Bihar, Uttar Pradesh, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir in India and the North-West Frontier in Pakistan and Eastern Nepal. The concentrated field works were performed in Orissa (1987, 2001), Karnataka and Andhra Pradesh (1996, 2001).

Table 3. Expeditions of millet research in the Indian subcontinent between 1983 and 2001

Year (month)	Locality	Research Team
1983.9-11	Nepal, India (Hariana)	The Japanese Scientific Expedition for Nepalese Agricultural Research
1985.9-11	Pakistan (Northwest province), India (Karnataka, Andhra Pradesh, and Tami Nadu)	Kyoto University Scientific Expedition to the Indian Subcontinent
1987.9-11	India (Jammu and Kashmir, West Bengal, Orissa, and Assam), Pakistan (Sind)	Kyoto University Scientific Expedition to the Indian Subcontinent
1989.9-10	Pakistan (Azad Kashmir), India (Karnataka, Madhya Pradesh, and Maharashtra)	Kyoto University Scientific Expedition to the Indian Subcontinent
1996.9～97.6	India (Karnataka, Andhra Pradesh, Tamil Nadu, Orissa, Himachal Pradesh, and Utter Pradesh)	Research abroad supported by Japanese Government, University of Agricultural Sciences at Bangalore
2001.9-10	India (Karnataka and Orissa)	Tokyo Gakugei University Scientific Expedition to the Indian Subcontinent

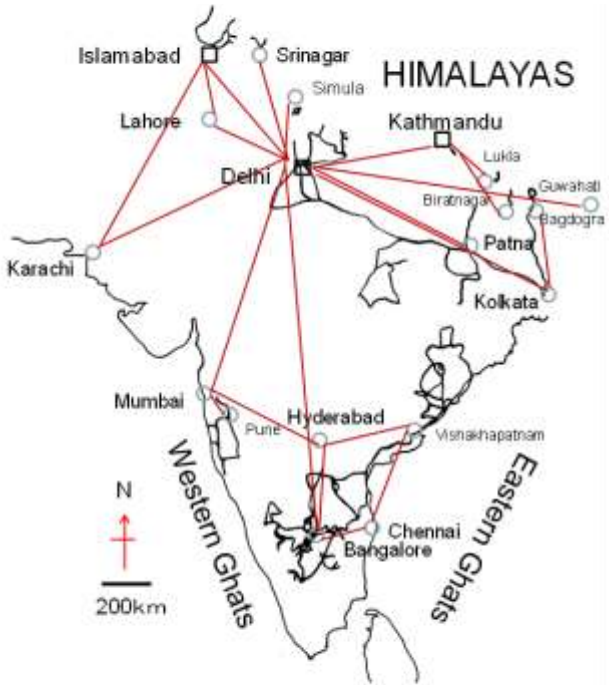


Figure 1. Expedition routes in the Himalayas, Western/Eastern Ghats

Procedure of research studies

The scholars such as Frazer (1911) and de Candolle (1883) had drawn specific information from numerous books, and deduced their hypothesis on the origin of domesticated plants. While the other scholars such as Vavilov (1926) and Kihara (1954) had conducted field researches and botanical experiments, they had induced their theory based on the results. Sakamoto (1988) had conducted field researches and eco-genetical experiments which had used many accessions collected. Those accessions were domesticated plants and the relative species for using materials under experimental condition.

The following wild species of Poaceae are gathered for grain food in the savanna aera, Africa. Those are so many, 33 species; genera *Aristida* (1 species), *Becheropsis* (1), *Brachiaria* (4), *Cenchrus* (2), *Dactyloctenum* (1), *Digitaria* (1), *Echinochloa* (3), *Eleusine* (1), *Eragrostis* (2), *Eriochloa* (1), *Hyphrrhenia* (1), *Latipes* (1), *Loudetia* (1), *Oryza* (1), *Panicum* (3), *Paspalum* (1), *Saccolepis* (1), *Setaria* (2), *Sorghum* (1), *Sporobolus* (1), and *Urochloa* (2) (Nakao 1967). These are mostly perennial plants which makeup main component growing in the grassland and wetland. However, annual plants are included around the savanna area. The first stage of pre-farming had been stared through gathering grains of annual plants. After that the following stage of semi-domestication, via cultivation including transplanting, weeding, plowing, etc. On the stage of domestication, farmers had conducted sowing, harvesting, processing and then cooking. The perennial plants, Poaceae are also gathered now, but they have been discontinued to domestication process. For example, 35species of genus *Setaria* are perennial plants in Africa, but these species had not domesticated (Nakao 1967). It is clear that annual plants are very important for domestication.

On the first of all my research plan, I had conducted the comparative studies on annuals and perennials. I had made the list of annuals and perennials belonging the same genera through the botanical encyclopedias. Then I had selected genera *Mazus*, *Cardamine*, *Rorippa*, and *Secale* for the evolution from perennial to annual, and more genera *Agropyron*, *Coix*, and *Oryza* for the ecological change from perennial to ecological annual. These comparative studies are written in Chapter 2.

The next, I have studied the domestication process and dispersal route of Common millet (*Panicum miliaceum*) as an ancient domesticated millet in all Eurasia (Chapter 3). The comparative study on the Indian original millets was conducted including morphological/ecological characteristics, analysis in biological components, genetical analysis of characters by artificial out crossing (Chapter 4). I had learnt the new technic of experimental methods, and then I had analyzed experimentally each species in the biological level from the population to the molecular (Chapter 4).

The third, changing the sight of research for the food processing/cooking methods, I had studied on their characteristics of resource and dispersal in each locality (Chapter 5). Finally, I propose the new model of hypothesis on the domestication processes and dispersals of millets/grain crops around Indian subcontinent (Chapter 6).

The conservation activities of biocultural diversity

I organize the materials of agricultural complexes and release them on my website which is registered the National Diet Library.
{http://www.ppmusee.org/goods.html and https://www.milletiimplic.net/index.html}

Chomin Nakae said that the most of Japanese academics were had imported and translated

foreign books. Because we cannot understand many languages, the translated books are very comfortable. However, if the translation is wrong, it is necessary we will be required to read again the context by the original book. On the other hand, because it is seldom that the Japanese translators translate the Japanese book to some kind of foreign language, we must write our book and papers mostly in English for foreign readers.

I have been guided by Nakao' conceptional ideas (imagination) and Sakamoto' self-reliance (screwball), and then I have conducted many botanical experiments and wandered many places around 55 years. In the Indian subcontinent, I have been a member belonging to the research teams of Kyoto University, Tokyo Women's Christian University, Tokyo Gakugei University and so on (from 1983 to 2001). Also, I was an oversea research fellow belonging to University of Agricultural University (Bangalore, India) from 1996 to 1997. Moreover, I was an oversea research fellow belonging to University of Kent (Canterbury, UK) and Royal Botanic Gardens, Kew for collecting materials from 2005 to 2006. After my retainment (2014), I was a fellow belonging to Research Institute for Languages and Cultures of Asia and Africa, Tokyo University for Foreign Studies (from 2014 to 2019). I have studied Indian culture and archeology.

Within my short life, I have considered the importance that we must inherit biological diversity and traditional culture as an integrated cultural complex through the research on the domestication process of millet. It is suggestive and insightful that Shiva (1993) had written the phrase 'Diversity as a way of thought as a way of life is what is needed to go beyond the impoverished monocultures of the mind,' in her book "Monocultures of the mind." She had suggested that our minds had become week by the decline of our biocultural diversity.

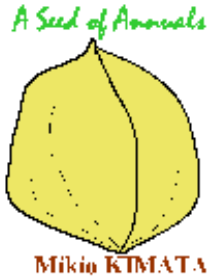
We have conducted some projects, for example, workshops/seminars of millet farming, designated activities of Globally Important Agricultural Heritage Systems 'Millet Street.' As one of our activities on Plants and People Museum, we returned the seeds of local variety to farmers, if they had lost it. We had proposed a position paper, 'People and Seeds for the Future: The importance of conservating plant seeds for the sake of bio-cultural diversity' to CBD/COP10 in Nagoya (2010).

In the next year 2011, the Great East Japan Earthquake occurred, and then the nuclear reactor of Fukushima nuclear power plant collapsed. The radioactive material scattered in all directions including Tokyo. In order to avoid this pollution for plant genetic resources, immediately I had sent and transferred them (about 10 thousand accessions of millets) to Ryal Botanic Gardens, Kew, UK.

I have mostly spent my life for the study on millets, their conservation and popularization. However, Japanese people did not recognize the importance of millet and they did not evaluate the research on learning environment and biocultural diversity (Chapter 7). Most Japanese people have become a monoculture in their mind. Because they had lost their prides as self-sufficient farmers, they have indulged in their parasitic lives such as only consumers. The food security is the first priority in our daily life, but money is everything in the present world. The orphan millets have been neglected by deep-rooted prejudice even at rural hill area where their ancestors had grown many kinds of millet. It is a meddling that we suggest the daily life for connecting hope.

However, I hope that everybody thinks deeply again for your family, local community and country for becoming happy. It is a pure, peaceful and beautiful life. I have kept company a few of intelligent farmers, who have indulged themselves in rural life.

Chapter 2　Plants and people in the Quaternary



Most people are very interested in the ancestral species of domesticated plant, but they never know the domestication process among plant and human being. They are not curious about our coevolution between plants and human being. Then I have conducted botanical experiment and field research on growth habit, reproductive system such as very important characteristics on the domestication process. I did not apply only to Poaceae, also I used some genera for comparative studies on growth habit and reproductive system. Moreover, I had done form ecogenetical study to molecular analysis of biological component.

Comparative ecological genetics on annuals and perennials

Nakao (1967) and de Candolle (1883) had suggested that the research on the evolution of annual was very important for explaining the origin of domesticated plant. I had known now that their excellent idea had been connected with my issue of doctoral thesis (Kimata 1980) 'Studies on the Comparative ecogenetics of annual and perennial plants.' Sakamoto had given me the ecogenetical study on the aspect which annual had evolved from perennial.

As shown the evolution of plant in Figure 2, the C4 plants had emerged in tertiary era, about 7 million BP, and then the perennial herb had appeared in Neogene. Subsequently the annual herb had appeared in Quaternary, 2.58 million BP. The annuals had survived by seed dormancy under the severe conditions which were cold, hot and drought. The reproductive systems of plants had become remarkably diversified for responding the environmental change. Synchronically, the ancestral genus *Homo* had appeared around Quaternary. Also, the gregarious animals had adapted and settled in grassland.

The most of Perennials I are cross-fertilized and self-incompatible species. Perennials II are cross-fertilized species, or sometimes are able to parthenogenesis. Perennials III are only parthenogenesis. Perennials IV are cross-/self-fertilized and self-compatible. Annuals had evolved from Perennials IV. Annuals are self-fertilized and sometimes cross-fertilized. Annuals can produce numerous seeds. The general characteristics of annuals and perennials are compared in Table 3. However, it is very difficult to say simply, as each plant species have diverse habits.

Evolution from annual to perennial plants

The evolution process of plant growth habit from perennial to annual have been very important, because the grains are mostly annual or annual-like under cultivating condition.

The reproductive systems of annual and perennial species are usually quite different (Baker 1955, 1959, 1974; Stebbins 1957, 1958, 1974; Ehrendorfer 1965; Harper 1967; Antonovics 1968; Harper and Ogden 1970; Kawano 1974; Jain 1976). The reproductive strategy of annuals is only that

of sexual reproduction by seed, while that of perennials is composed of the sexual and/or vegetative modes. Annuals are often self-pollinated, while perennials often cross-pollinated. Moreover, self-pollinating taxa usually appear to have been derived from outcrossing relatives, and annuals from perennials. Generally, it is thought that the homozygous genotypes by inbreeding sacrifice the evolutionary capacity for a change. However, there is another explanation that the evolution of inbreeding is not purely accidental, but is actually favored by natural selection because selfers possess some advantages over crossers under certain conditions.

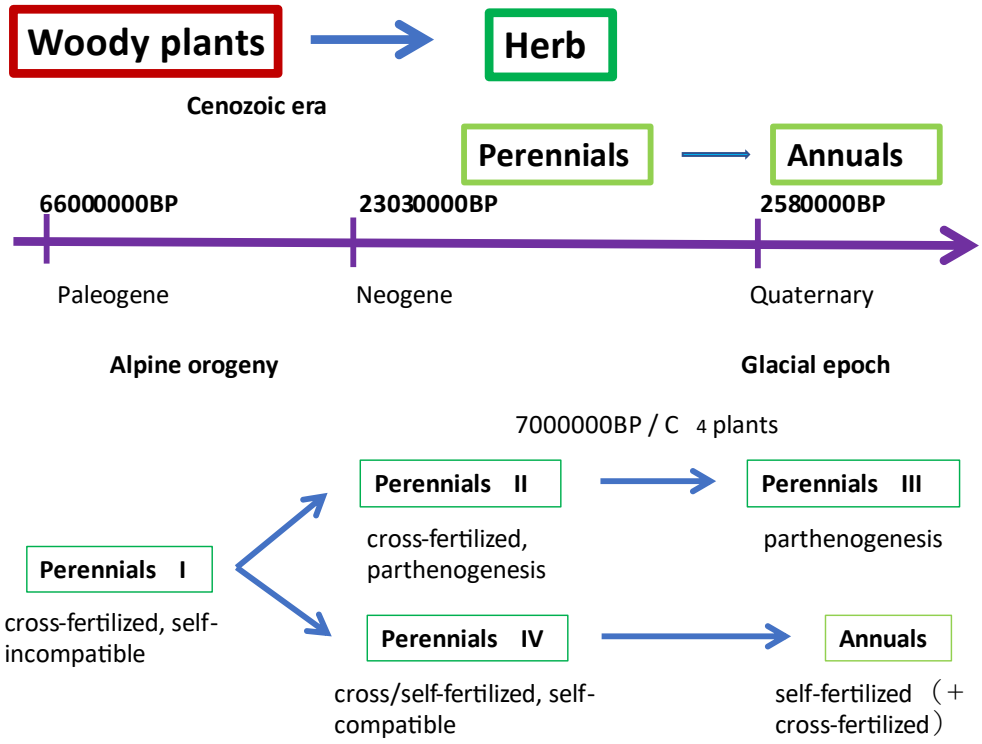


Figure 2. Phylogenetic evolution of herbaceous plants

Roughly speaking, annual plants are self-fertilizers, the flowers are small, whitish, so many, and these produce numerous small seeds as shown in Table 3. The self-fertilization reduces genetical variability, but the polyploidy preserves biodiversity. Annuals colonize into habitats disturbed by nature or human being. The self-fertilization guarantees for becoming a colonizer and pioneer. Most annuals have C_4 pathway and the energy product allocates much to seeds. The phenotype indicates wide range of degrees by the environment. Those characteristics had effectively worked for domestication process.

On the other hand, perennials indicate contrasting characteristics. Perennials are mostly cross-fertilizer, and at the same time they carry out both seed and vegetative reproduction. Those spices are diploid and C_3 pathway in general. In rare cases, the interspecific hybrids between annual and perennial species in same genus are rarely occurred. As some results in the following experiments, perennial was genetically dominant, while annual was recessive. Moreover, *Oryza sativa*, *Coix lacryma-jobi* subsp. *ma-yuen* and *Paspalum scrobiculatum* were botanically perennial, but became ecologically annual and non-shattering through artificial selection.

Table 3. Comparison between annual and perennial reproductive systems

Character	Annual	Perennial
Pollination system	self-pollinated	cross-pollinated (self-incompatible)
Flowers	smaller, monocolored (whitish)	large, polycolored
Pollen grains	fewer	many
Anthers	adjacent to stigma	distant from stigma
Asexual reproduction	absent	present
Flowering	quick	slow
Germination	quick	slow
Sexual reproduction by seed	many	fewer
Seed weight	light	heavier
Polyploidy	high	mostly diploid
Plasticity in phenotype	high	low
Photosynthesis	many C4 pathway	C3 pathway
Habitat	disturbed	stable
Energy allocation	much seeds	vegetative organ,
growth habit	dominant	recessive

In the domestication process as evolution involved artificial and natural selections, the important characters of annual were reproductive systems (self-/cross-fertilized, vegetative), size and number of seeds, photosynthesis circuit (C_4 or C_3), energy allocation, and so on. The annual life cycle of grain crops had been closely related to seed production (Table 4).

Compared with perennials, annuals do not vegetative propagation (few exceptional cleistgamy), have a lot of small whitish flowers by sexual reproduction, and a few pollens for self-fertilizer. Annuals are mostly self-fertilizers (sometimes cross-fertilize), produce numerous seeds, and can make big population through only a seed. The self-fertilization decreases genetic variability, but polyploidy increases and accumulates genetic variability. For example, the self-pollination rate of *Zea mays* is very low, about 5% because of anemophilous flowers and hermaphrodite. *Coix lacryma-jbi* and *Pennisetum americanum* are cross-fertilizers with protogyny. *Sorghum bicolor* is self-fertilizer. Generally speaking, fruits Brassicaceae plants are self-incompatible, they cannot pollinate by own pollens. However, surprisingly the self-pollination rate of *Oryza sativa* is almost 100% in spite of perennial.

Table 4. Comparison between cross-fertilizer and self-fertilizer

	Cross-fertilizer	Self-fertilizer
Pollination system	cross-pollination, self-incompatible	self-pollination, self-compatible
Recombination	low	high
Polyploidy	diploid	polyploid
Flower	colorful, aroma, nectar gland, honey beacon	monochromatic, white, degeneration
Pollen	many	few
Fruit	partially fruited	plentiful fruited
Distribution	narrow	wide

Annuals grow in seasonal semi-arid regions for example the savannah or Mediterranean area, and human living area i.e. habitats disturbed frequently in growing environment. Summer annuals are dominant under the savannah climate, local people had domesticated many kinds of millet and then constructed Savannah Agricultural Complex. On the other hand, Winter annuals are dominant under Mediterranean climate, local people had domesticated many kinds of wheat, Triticeae and then constructed Mediterranean Agricultural Complex. Moreover recently, yearlong annuals have adapted to artificial environment under the urban area. Each plant dies after flowering and fruiting within a year, but the population inhabits through all seasons, i.e. yearlong annual, *Mazus japonicus*,

Perennials grow at non-disturbed and stable habitats, in forest, mire, wetland. These reproductive systems are both vegetative and sexual reproduction. They produce a lot of pollens but a few flowers which are bigger and colorful. Perennials sometimes include self-incompatible species, many diploid plants, and a few big seeds.

C_3 plants carry out photosynthesis only by carboxylic acid cycle. Their photosynthetic product is trimonosaccharid (3-sulfoglyceric acid) in the first step. There are so many plants, *Oryza sativa*, *Triticum aestivum*, *Glisin max*, *Brassica napus* and so on. C_4 plants carry out photosynthesis initially by C_4 pathway (dicarboxylic acid cycle) and subsequently by carboxylic acid cycle. These are about 20 families and 3000 species including families Poaceae, Cyperaceae, Amaranthaceae, Chenopodiaceae in the tropical and subtropical zones. The photosynthesis rate of C_4 plants is higher than those of C_3 plants. Moreover, the utilization efficiency of C_4 plants is higher than C_3 plants on water and nitrogen. (https://www.jaicaf.or.jp)

The growth habits of weeds growing in Japan are shown in Table 5 (Kasahara 1974). The rate of native annuals is over 40% of weeds in Japan (344 species including prehistoric naturalized plants), and also the rate of native perennials is about 40%. The rate of naturalized annuals is about 15% and the rate of naturalized perennials is about 6%. On the latter naturalized case, the rate of annuals is 2.5 times more than the rate of perennials. Summer annuals have been companion weeds for rice paddy fields, while winter annuals have been companion weeds for wheat fields. When new coming weeds invaded into disturbed habitats, namely the annuals were advantageous for becoming naturalized weeds.

Table 5. Growth habits of weeds in Japan

Growth habit	Native species	Naturalized species	Total
Summer annual	131 (29.8%)	33(7.5%)	164(37.2%)
Winter annual	32(7.3%)	24(5.5%)	56(12.7)
Summer/Winter annual	13(3.0%)	11(2.5%)	24(5.5%)
Perennial	165(37.5%)	27(6.1%)	192(43.6%)
Perennial/Annual	2(0.5%)	1(0.2%)	3(0.7%)
Tree	1(0.2)	0(0%)	1(0.2%)
Total	344(78.2%)	96(21.8%)	440

Kasahara 1974

The ancestral and relative species of domesticated grain crops have grown all around our habitats as indicated in Figure 3. For example, *Setaria viridis* is the ancestor of *S. italica* and both species make hybrids. *Setaria pumila* is the same species as the ancestor of kolati, *S. pumila* in Eastern India. *Coix lacryma-jobi* subsp. *lacryma-jobi* is the ancestor of *Coix lacryma-jobi* subsp. *ma-yuen*. *Echinochloa crus-gali* is the ancestor of *E. utilis*.

Digitaria iliaris

Coix lacrymaobi

Paspalum thunbergii

Setaria viridis

Echinochloa crus-galli

Penisetum alopecuroides

Setaria pumila

Eragrostis ferruginea

*Avena **fatua***

Hordeum murinum

Sorghum halepense

Agropyron tsukushiense

Figure 3. Weeds relating to domesticated plants in nonboring sites.

Ecological genetics on five genera

Most annual plants have the ability to set many seeds by autogamy (Baker 1974). Moreover, with self-fertilizers a single individual can establish a colony even on a temporarily disturbed habitat long-distance dispersal (Baker 1955, 1959; Stebbins 1957, 1958; Antonovics 1968; Lefébre 1970; Jain 1976).

Perennial species are often cross-fertilized and mostly polycarpic plants which have lived over a year. On the contrary, annual species are the monocarpic which complete their life cycle and die within a year (Harper and White 1974; Harper 1977). The reproductive strategy of annuals is only that of sexual reproduction by seed, with few exceptions, while that of perennials is composed of the sexual and vegetative modes (Baker 1959; Harper 1967; Harper and Ogden 1970; Kawano 1974).

The reproductive allocation of dry matter into the seeds is considerably higher in annuals than in perennials. On the contrary, only in perennials the reproductive allocation into the vegetative propagules or storage organs is often very high (Eherendorfer 1965; Harper 1967; Harper and Ogden 1970; Kawano 1974, 1975; Ogden 1974; Kawano and Nagai 1975).

The seasonal variation in the population density of summer annuals has been studied in both cases in which winter annuals existed and did not exist (Raynal and Bazzaz 1975). However, it has hardly been studied in the sympatric habitat, where annual species have grown with the related perennials.

In an attempt to clarify the ecogenetical characteristics of annual species and their perennial relatives, comparative studies in five genera of the following plants, *Mazus*, a genus of the family Scrophulariaceae; *Cardamine* and *Rorippa*, Cruciferae; *Agropyron Coix, Secale* and *Zea*, Gramineae, were conducted. It is emphasized that these comparative ecogenetical studies in these five plant genera provide some critical information concerning the ecogenetical aspects on the origin of weeds as well as domesticated plants.

Comparison of life history strategy and reproductive system between *Mazus japonicus* and *M. miquelii*, Scrophulariaceae

Family Scrophulariaceae have been dispersed 210 genera and 3000 spices in the world. There are 10 spices of genus *Mazus* in the world and 3 species in Japan (Satake 1964). *Mazus japonicus* (Thunb.) O. Kuntze is an annual weed which has distributed over the temperate or tropical zones from Afghanistan to China and Japan, Shino-Japanese floral region. *M. japonicus* had been naturalized to the East Cost a hundred years ago, but *M. miquelii* had been naturalized about 50 years ago. It is unknown where these species distribute in the United States today (Michener personal communication 1977). *M. miquelii* Makino is a perennial weed which has distributed from Central China to the southern Hokkaido in Japan. *M. faurei* Bon. has grown in the south Kyushu, Okinawa and Formosa (Kitamura and Murata 1964). I have not seen this spices in Kagoshima, Miyazaki and Okinawa. *M. pumilus* (Burm. f) Steenis is a synonym of *M. japonicus*. Moreover, *M. goodcnifolium* (Hornrm.) Pennell and *M. quadriprotuberans* N. Yonezawa (1998) grow in Japan

Mazus japonicus (Thunb.) O. Kuntze was collected and observed in Koganei-shi and Kunitachi-shi, Tokyo, and *M. miquelii* Makino in Hino-shi and Kunitachi-shi, Tokyo. Voucher specimens are

deposited at the Herbarium of Tokyo Gakugei University (Figure 4). At the same time in Kunitachi-shi *Vandellia crustaceae* Bentham and V*eronica persica* Poir. were also observed for the comparison with *M. japonicus*. *M. japonicus* (annual) and *M. miquelii* (perennial) grow sympatrically in rice paddy fields. There life history strategies were compared on the base of relation between reproductive systems and population dynamics in the sympatric habitat (Kimata 1978; Kimata and Sakamoto 1979).

Figure 4. *Mazus japonicus* and *M. miquelii* on the levee of paddy field

A close relation between the number of blooming flowers and the number of visiting pollinators was observed in *M. miquelii.* On a sunny day the mode of blooming flowers was consistent with that of the frequency of visiting pollinators. The reaction time of stigma seismonasty in *M. miquelii* has a tendency to be longer during the day than during the night, but on the contrary, the recovery time had a tendency to be shorter during the day than during the night. Therefore, it is clear that the stigma lobes close more slowly and open more quickly during the day than during the night. Since most pollinators visit flowers during the day and since stigma seismonasty is lost by pollination, it is assumed that the stigma seismonasty observed in *M. miquelii* is an adaptation to cross-pollination by insects.

The growth habit (annual or perennial) of a given plant species is usually determined through field observation. However, the growth habit can be exactly determined only through experimental studies. If it is an annual species, the plants must die without a dormant bud formation after the flowering and fructification in the natural state. *M. japonicus* did not die through low temperatures or frost but died after fructification. This clearly indicates the annual growth habit of *M. japonicus.* According to field observations of natural populations of this species, individuals in different stages of growth were found in the populations almost all the year round. Seed germination occurs from April to October successively and flowering also takes place similarly. On the contrary, *M. miquelii* is a perennial species because this species produces many ramets through stolon formation. Flowering of this species is mainly controlled by the temperature. The time of flowering was observed twice in natural populations. In the spring from April to May, the plants, produced asexually in the autumn of the previous year, bloom abundantly and produce many seeds in this period. From August to October only, a few plants, germinated in May to June, produce flowers on the top of the stolons. Most plants in natural populations in this period produce many ramets

asexually.

The difference of pollination systems in *M. japonicus* and *M. miquelii* is also indicated by the pattern of seed production in these species. A capsule of self-pollinated *M. japonicus* produced more seeds but the variation in the number of seeds was smaller than found in *M. miquelii.* Moreover, seeds of *M. japonicus* were smaller and lighter, and this species may be more adapted to an effective seed dispersal. In *M. miquelii,* on the other hand, a small number of seeds per capsule is produced and the number is more variable than in *M. japonicus.*

There were two flowering seasons in *M. japonicus* which was a year-long annual. The seeds were produced mainly twice in spring and autumn by the plants of winter and by those of summer population, respectively. In the winter population there were two grades of plant size. The number of seeds produced by a summer plant (9,105 grains) was about three times as many as by a small plant in winter population (2,929), but was only about a fifth as many as by a large plant (51,241) which was germinated in summer by chance. Namely, if the mean value of seeds was estimated as an individual in winter population, the number of seeds in a summer plant was approximately as many as that in a winter one. Generally, in a summer population *M. japonicus* produced mostly seeds during autumn because of the high population density, and in a winter population it did many seeds during spring, then the seeds of winter plants germinated and became summer plants.

M. miquelii had two flowering seasons, and in spring produced 3,638 seeds, but in autumn only 60. In spite of 94.2% pollen fertility, the latter plant which formed by seed had just 16.7% seed fertility because of low activity of pollinators under the low temperature condition. Therefore, the seed production of *M. miquelii* was only a third as many as that of *M. japonicus* even in spring.

However, at the same time *M. miquelii* propagates asexually by stolon formation which might compensate for the smaller production of seeds and thereby maintain the natural populations in this species. The plant formed by ramet produced ca. 300 new ramets in May-October. On the other hand, the plant formed by seed could hardly contribute to the magnification of a species population in the first year, because few seeds and small number of ramets are produced by it.

Reproductive systems of two *Mazus* species

Mazus japonicus is a self-pollinated species, while the breeding behavior of *M. miquelii* mostly cross-pollinated with a low degree of self-incompatibility (Table 5). The pollination size of the upper anthers and the pollen fertility of the upper and lower anthers were not important factors because such differences were not statistically significant between the two species. However, it was suggested that the pollen fertility of upper anthers was effectively concerned with self-pollination in *M. japonicus,* since the pollen fertility of the upper anthers was significantly higher than that of the lower anthers at 1% level. The quotient of under-lip length of stigma lobes showed a remarkable difference between the two species. This indicates that the under-lip of the stigma lobes of *M. japonicus* develops markedly. The curved tip of the under-lip of the stigma lobes is self-pollinated by the half wrapping of the upper anthers. On the contrary, *M. miquelii* is not self-pollinated, because the under-lip of the stigma lobes of this species does not develop so much, and the stigma shows stigma seismonasty. Stigma seismonasty has been observed in the Scrophulariaceae, Ranunculaceae, Pedaliaceae, Bignoniaceae, Capparidaceae and Maryniaceae. *M. miquelii* is one of the examples found in the Scrophulariaceae. It has been suggested that this phenomenon is closely related to cross-

pollination by insects and to promotion of pollen germination on the stigma (Yoshinaga 1890; Miyoshi 1891; Newcombe 1924; Watanabe 1969).

Table 5. Reproductive systems of *Mazus miquelii* and *M. japonicus*

Species	Spring	Flowering season	Summer	Autamun	Winter	Growth habit
	rosette, bolting	winter form flowering, fuluiting, dead		germination	rosette	
Mazus japonicus		germination, growth in summer, flowering/fruiting.	germination, growth in summer, flowering/fruiting .dead			year long annual
Mazus miquelii	rosette, bolting	flowering and fruiting, seed germinating	elongating stolons, formating many ramets (vegetative reproduction)	flowering, making rosette, seed germination	rosette	perennial

Population dynamics of annual weeds

There are three types of annual species, e.g., summer, winter and "year-long" annuals. *Vandellia crustacea* is a typical summer annual, for the plant of this species lives from June to November. *Veronica persica* is a typical winter annual, for the plant lives from September to the following June. On the contrary, *M. japonicus* was a summer and winter annual, i.e., a year-long annual because the population has been maintained all year-round, notwithstanding that each individual of the population germinated and died within a year. These three species were all annual species even physiologically.

Veronica persica and *M. japonicus* showed a bimodal pattern of seed germination with two peaks of plant density in November-December and March-April, and in November and June-July, respectively. This phenomenon was observed in *Setaria faberii* Herm. which seemed to have two seed populations differentiated on the basis of time of germination (Raynal and Bazzaz 1975). There is no evidence for yet whether the mortality of *Veronica persica* and *M. japonicus* is dependent upon population density or not. However, their mortality was apparently affected by drought and frost condition.

The population of *M. japonicus* had a long flowering period, nearly all year-round, in spite of being an annual species under the artificial and natural conditions. There were more inflorescences in summer plants than in winter ones. Therefore, most seeds were produced during summer.

As mentioned in the previous section, it is apparent that *M. japonicus* is a self-pollinated species, while *M. miquelii* is a mostly cross-pollinated one with asexual reproduction by stolon. It is predicted, therefore, that this difference of reproductive behavior in two *Mazus* species affects their population dynamics. These dynamics in the sympatric habitats, the rice paddy fields, appear to hold the key to the solution of the following problem; annual species are better colonizers than perennial ones in disturbed habitats as they produce many seeds reliably by self-pollination and establish new populations rapidly (Baker 1955, 1959; Stebbins 1957, 1958; Antonovics 1968; Lefèbvre 1970; Jain 1976).

The results give a model of the population dynamics. Four stages can be illustrated: 1) rice cropping; on the levee, there were about 3 plants of *M. japonicus*/m^2 and about 100 plants of *M. miquelii*/m^2. In the non-cultivated paddy field, there were about 3 plants of *M. japonicus*/m^2 only in winter. 2) non-cropping (relinquishment); *M. japonicus* colonized into the abandoned paddy field by seeds. On the contrary, *M. miquelii* invaded from the levee to the abandoned paddy field by stolons. 3) ill-drained abandoned paddy field; *M. japonicus* decreased (about 50 plants/m^2 in the center) and *M. miquelii* increased by stolons (about 350 plants/m^2 near the levee). This pattern may be presumed by the density of two species in the parts near the creek. 4) well-drained abandoned paddy field; *M. japonicus* increased by seeds (about 350 plants/m^2 in the center) and *M. miquelii* decreased (a few/m^2 even near the levee).

The population dynamics in the two *Mazus* species seemed to be dependent on the competition among other species, their seed germination, and the rooting (ramet formation) from node of stolon in *M. miquelii.* The number of species on the levee was twice as many as in the fallow paddy field. Therefore, on the levee the density of two *Mazus* species might be difficult to increase by seeds, because those which light germinators could hardly germinate in the shade of other plants, or even if germination was possible, their seedlings may have soon died. However, *M. miquelii* could reproduce on the levee by stolons.

As grasses were dominant on the abandoned levee, there were only 29 plants of *M. miquelii*/m^2. Moreover, there were 108 plants of *M. japonicus*/m^2 in the abandoned paddy field, for annual weeds were dominant here.

By comparison with the seed germination of two *Mazus* species, M. japonicas was able to germinate better under several temperature and under lower soil moisture conditions than was *M. miquelii*. However, the seed germination of *M. japonicus* occurred more rapidly than that of *M. miquelii*. The rooting from the node of stolon in *M. miquelii* required less soil moisture (34.4%) than the seed germination (79.1%). Consequently, *M. japonicus* was a better colonizer than *M. miquelii* in disturbed habitats. There was an abundance of plants of *M. miquelii* only on the levee, a relatively stable habitat.

In the winter plants of *M. japonicus* the first flowered capsule seeds were germinating more rapidly than the 4^{th} and 8^{th}. On the contrary, in summer plants the 8^{th} flowered capsule seeds were germinating more rapidly than the 1^{st} and 4^{th}. Specifically, it appeared that the germination requirements differ widely among seeds. This fact may be related to the vigorous germination in May-July and the variety of seed germination.

Life history strategy of two *Mazus* species

The schematic model of the life history of *M. japonicus* and *M. miquelii* is shown in Fig. 11.

M. japonicus is an year-long annual and self-pollinated species. This species reproduces by numerous seeds and grows on upland fields, roadsides, and so on. There is the first main period of seed germination in April-June. The summer population is composed of the seedlings which are grow from the seeds of winter plants or the buried ones. These seedlings grow rapidly in summer and then flower, fruit, and disperse numerous seeds in June-October. There is the second main period of seed germination in September-October. The winter population is composed of the seedlings which are grown from the seeds of summer plants or the buried ones. These seedlings grow leisurely

in winter and then flower, fruit and disperse numerous seeds in April-June.

As the germination of *M. japonicus* was not homogeneous, the age diversity was very high in a garden population. Plant height, the number of leaves and the number of inflorescences had specially high diversity (c.v.). The length and width of the largest rosette leaf had rather low diversity. In summer large plants flowered and had died by November. However, a part of small seedlings might probably become large plants and then flower in next spring.

M. miquelii is a perennial and cross-pollinated species. This species reproduces mainly stolons and grow only on the levees of rice paddy fields. The wintered rosette plants flower, fruit and disperse many seeds in April-June. Moreover, they form many ramets by stolon vegetatively in May-October. Their ramets grow in autumn-winter and flower in the next spring. The seeds and buried ones germinate in May-June. These seedlings grow in summer, and then flower, fruit and disperse a few seeds in August-October. Similarly, they form some ramets by stolon in September-October. Their ramets grow in winter and flower in the next spring.

Compared with the seasonal change and percentage allocation of total dry weight throughout the life history of the summer population in *M. japonicus*, those of the winter population were characterized by the following three features; 1) the crude reproductive efficiency of the winter plant was rather lower than that of the summer one, 2) the winter plant stored a lot of substance in the roots during winter, but not the summer one, 3) at the end of growing period the dry weight of a winter plant was about three times as much as that of summer one. In short, the summer plant produced many seeds continuously with the storage of a little substance in roots, but the winter plant stored a lot of substance in roots during winter and began to produce many seeds in spring. This fact showed the difference between the life history of the summer plant and that of winter one in *M. japonicus*.

The mother plant of *M. miquelii* developed many roots and contributed to the elongation of stolons in May or September. The daughter plant (ramet) stored a lot of substance in roots during winter, and began to produce many seeds and new ramets by stolons in spring. On the other hand, the plant formed by seed hardly produced seeds, but did ca. 10 ramets in autumn. In the next spring these ramets flowered and produced many seeds and ramets by stolons. However, few plants formed by seed were observed in natural populations. These plants, therefore, could play only a secondary role in the life history strategy of *M. miquelii* two years after germination except that the genetic variability resulted from outcrossing would increase in their population.

The winter plant of *M. japonicus* and the daughter plant (ramet) of *M. miquelii* had such a character as stored much substance in roots during winter in common with each other. Moreover, all species of genus *Mazus* except *M. japonicus* are perennial ones which grow in winter and flower in spring-early summer (Peking Institute of Botany 1975). *M. japonicus,* therefore, might have been winter annual and then became a year-long one by the decrease of the seed dormancy and the early maturity from which the adaptation to the disturbed habitats resulted.

These series of studies in *Mazus* (Kimata 1978, 1979, 1986, 1991) might give a clue to the solution of problems on the life history strategy proposed by Harper (1967), Kawano (1975) and so on, i.e., concerning the longevity and expression of the life cycle, the program of energy allocation to reproduction and the number of seeds or vegetative propagules produced. *M. japonicus* is a self-pollinated annual species, while *M. miquelii* is a cross-pollinated perennial one. The former is a

wonderful colonizer and invades into the disturbed habitats. The clear differences of population dynamics in the sympatric habitat between *M. japonicus* and *M. miquelii* may indicate each characteristic in their reproductive strategy. Between annual species and perennial species there are the conspicuous differences of life history strategy which consists of the above ecological characteristics. These differences may have resulted from the adaptation to the environment of their habitats (Figure 5).

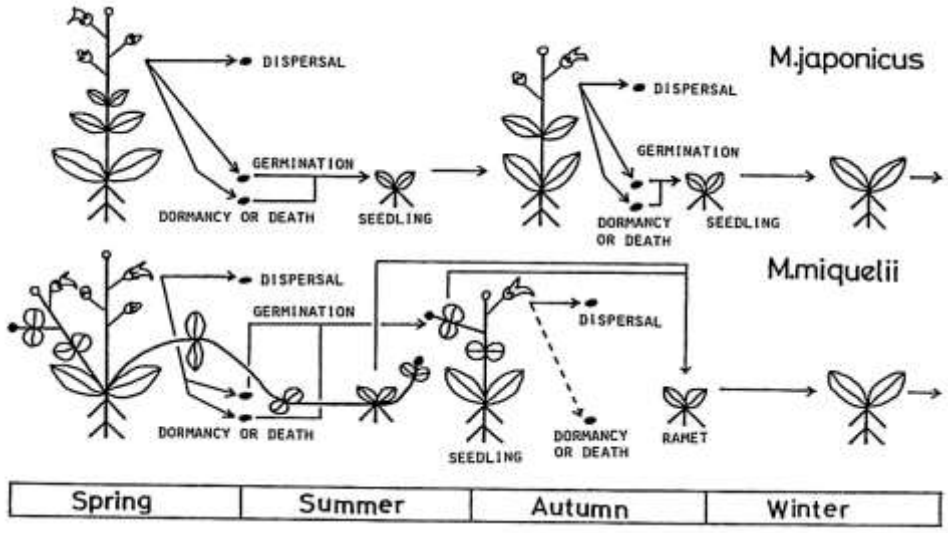


Figure 5. Schematic model of the life histories of *M. japonicus* and *M. miquelii*

● seed; ○ flower bud; ● shoot apex.

These experimental data on the life history strategies of two *Mazus* species could provide some further evidences for the evolutionary trend from cross-pollinated perennials to self-pollinated annuals in the flowering plants as a whole.

Comparison of reproductive systems in five species and subspecies of genus *Cardamine*, Cruciferae

The reproductive systems of *Cardamine flexuosa* ssp. *flexuosa* and ssp. *fallax, C. impatiens* (annuals), *C. scutata* and *C. lyrata* (perennials), were compared, in order to provide further evidence for the evolutionary trend from cross-pollinated perennials to self-pollinated annuals. Moreover, this study was devoted to obtain some information concerned with the intraspecific differentiation of a year-long annual type from a winter annual type in *C. flexuosa* (Kimata 1983).

Seven strains of *Cardamine flexuosa* ssp. *flexuosa* With. were collected mostly at fallow paddy fields in Tokyo, Kanagawa, Saitama, Chiba, Shizuoka and Kyoto Prefectures. Two strains of *C. flexuosa* ssp. *fallax* O. E. Schulz were collected at shady gardens in Tokyo. *C. impatiens* L. was collected at a forest floor of *Cryptmeria japonica* D. Don in Yamanashi Prefecture. Five strains of *C. scutata* Thunb. were collected mostly at creeks in Tokyo, Shizuoka and Kyoto Prefectures. Two strains of *C. lyrata* Bunge were found at paddy fields in Aichi and Mie Prefectures (Figures 6 and 7). More than 20 plants were collected in each strain, while, 10 plants were examined, and the remaining plants were placed on file with the Herbarium of Tokyo Gakugei University.

C. flexuosa and *C. impatiens* are self-pollinated annual species, *C. sucutata* is a cross-pollinated perennial species, and *C. lyrata* is a cross-pollinated perennial species with self-incompatibility. The perennial species may be either cross- or self-fertilized depending on the species. The evolutionary trend of breeding system may progress from cross-pollinated perennial with self-incompatibility to self-pollinated annual via self-pollinated perennial without self-incompatibility. Also, the above trend is shown clearly in the present four species of genus *Cardamine*.

Figure 6. *Cardamine flexuosa*
a, in paddy field; b, shady garden; c, on rock fence;
d, artificial hybrid F1 between two subspecies.

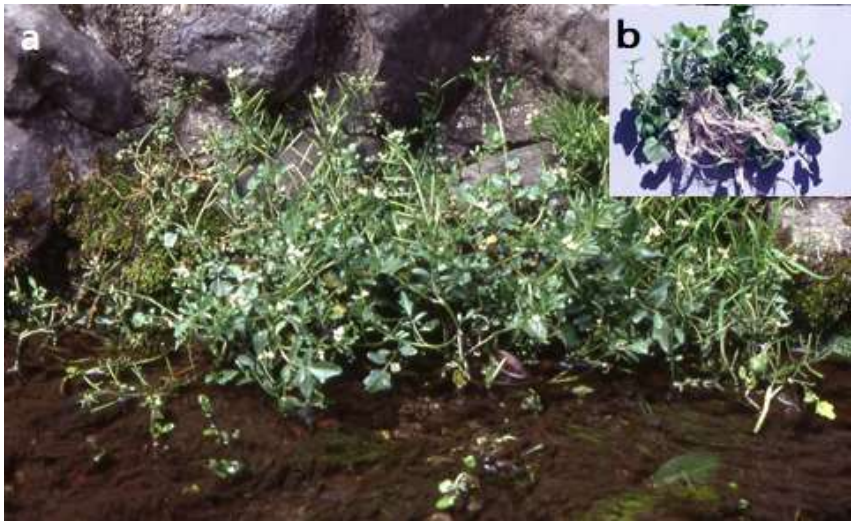


Figure 7. *Cardamine sucutata* in stream
a, flowering; b, rosette

The self-pollinated annual species are usually better colonizers in disturbed habitats, because massive seed production in the early stage of colonizing process plays an important role in the establishment of new populations (Stebbins 1958; Ehrendorfer 1965; Antonovics 1968; Lefèbvre 1970). Two subspecies of *C. flexuosa* well adapt to disturbed habitats. *C. flexuosa* ssp. *flexuosa* flowers in February-April and produces a great deal of small seeds which fall near its own stump in paddy fields. The seeds are dispersed uniformly during the cultivation practice in the fields. They are kept there in dormant condition until autumn. On the other hand, *C. flexuosa* ssp. *fallax* flowers in February-April and in June-November. Many seeds produced, fallen evenly within a distance, and germinate in May-October after a short dormant period and establish summer and winter populations. Therefore, *C. flexuosa* ssp. *flexuosa* and *C. flexuosa* ssp. *fallax* may have different seed dispersal strategy. Friedman and Stein (1980) reported that the annual *Anastatica hierochuntica*, Cruciferae has two contrasting dispersal strategies (dispersal on the spot and to a distance) which are dependent upon the balance between rainfall and runoff. *C. impatiens* is a self-pollinated annual species but it has adapted to rather stable habitats such as muddy floor and margin of forests. C. impatiens in March-May and produces a great deal of small seeds which fall at a limited distance by the erect growth form. Watkinson (1978) reported that the dispersal distance strongly correlated with the height of the infructescence in a winter annual grass, *Vulpia fasciculate*. Actually, seeds of *C. impatiens* with tall infructescence are dispersed farther than seeds of *C. flexuosa* and *C. scutata* with low infructescence. Seed germination of *C. impatiens* occurs in August after short seed dormancy. *C. scutata* and *C. lyrata* have adapted well to the paddy field which is cultivated regularly, supplied much fertilizer, and muddy throughout the year. *C. scutata* flowers in February-April and August-September, and produces rather many seeds which fall evenly into water of creek within a distance. The seeds without dormancy germinate in May. *C. lyrata* flowers in May and produces a few seeds which fall down to water and they may be dispersed by floating (Figure 8). They germinate in autumn after a long dormancy. These results well indicate that the better colonizing species adapting to grow in the disturbed habitats are installed more efficient seed dispersal mechanism.

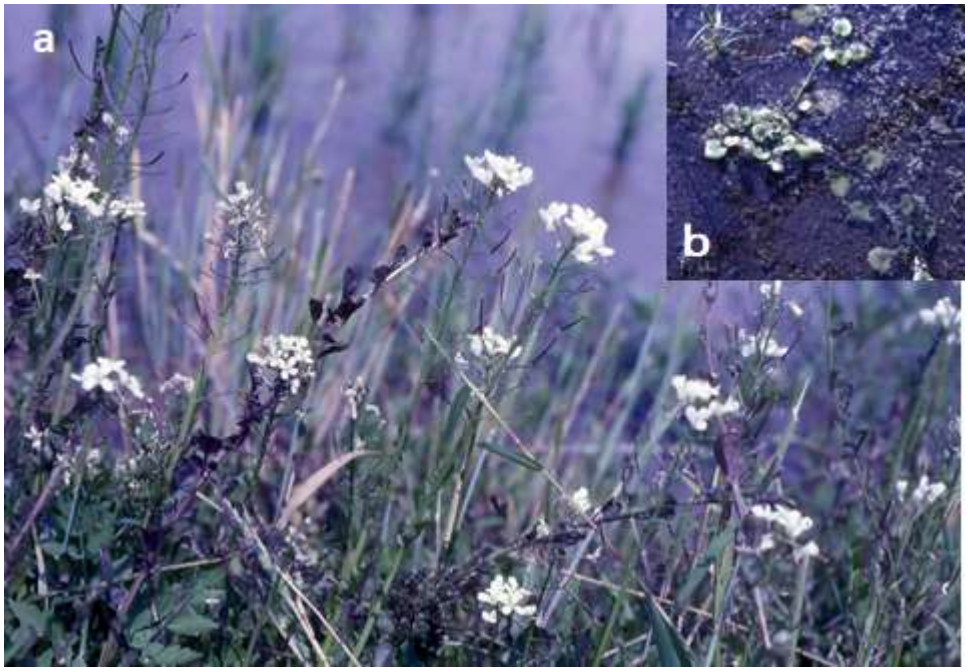


Figure 8. Cardamine lyrate in paddy field

a, flowering; b, ramets

The reproductive allocation of dry matter into sexual structures (e.g., seed) is considerably higher in annuals than in perennials. On the contrary, in perennials allocation into asexual structures (e.g., vegetative propagules and storage organs) is often very high (Harper 1967; Harper and Ogden 1970; Kawano 1974, 1975). In the present study a self-pollinated annual *C. flexuosa* allocates 26% of total dry matter into the siliques (a sexual structure). However, a self-pollinated perennial *C. sucutata* allocates only 12% of total dry matter into siliques and 48% into ramets (an asexual structure) at the end of growing season. A cross-pollinated perennial *C. lyrata* allocates less than 1% into siliques but 80% into stolons. Bell et al. (1979) determined the seasonal changes of biomass allocation in eight winter annual species. They described that 12-22% of total biomass locates in the roots until late flowering period when root allocation declined, and that maximum investment in reproductive structures attains 16-50% of total biomass. A winter annual *C. flexuosa* showed similar percentage allocation into roots and siliques.

The rooting ability of stem segment is higher in *C. lyrata* (75.0%) than in *C. flexuosa* ssp. *flexuosa* (17.5%) or *C. flexuosa* ssp. *fallax* (57.5%). However, it is very low (5.0%) in *C. scutata.* The weak rooting ability in *C. scutata* may closely relate to a low degree of vegetative reproduction. *C. lyrata* produces ramets about 27 times as many as *C. scutate* (Table 6).

Table 6. Vegetative propagation of genus *Cardamine*

Species	No. of plants	No. of vegetative propagules	
		Range	Average
Cardumine sucutata	20	1～12	4.6
Cardumine lyrata	8	87～167	133.3

These species of the genus *Cardamine* used in the present study are distinguished easily by several morphological characters. Among them the corolla of *C. lyrata* is about three times as large as that of other species. The larger corolla of this species may relate closely with its cross-pollination system.

In spite of complete intraspecific crossability, the subspecies differentiation of *C. flexuosa* occurs in several morphological and other characters, such as growing season, seed dispersal mode, germination period, flowering period, and so on, as shown in Table 7. *C, flexuosa* ssp. *flexuosa* can establish large population only in the restricted habitat, fallow paddy fields. On the other hand, *C. flexuosa* ssp. *fallax* can establish merely small population (a few per m^2) in spite of growing in the various habitats, i.e., gardens, roadsides and nurseries, because the present subspecies produces fewer seeds than the former subspecies and can establish only in rather wet microenvironments.

Table 7. Summary on reproductive system of genus *Cardamine*

Species	Spring	Flowering season	Summer	Autamun	Winter	Growth habit
Cardamine flexuosa	rosette, bolting	winter form flowering, self-pollination, fructfication, dead		germination	rosette	winter annual + year long annual
			germination, growth in summer,	summer form flowering/fructfication	dead	
Cardamine flexuosa ssp. fallax	rosette, bolting	flowering and fructfication, self-pollination, dead		seed germination	rosette	winter annual
Cardamine impatiens	rosette, bolting	flowering and fructfication, self-pollination, dead		seed germination	rosette	winter annual
Cardamine scutata	rosette, bolting	flowering and fructfication. self-pollination, self-compatible	vegetative propagation,	seed germination	rosette	perennial
Cadamine lyrata	rosette, bolting	flowering and fructfication. cross-pollination, self-incompatible	vegetative propagation by stolons		ramets, rosette	perennial

As discussed above, the annual growth habit is classified into three different types; summer annual, winter annual and year-long annual. *C. flexuosa* ssp. *flexuosa* is a winter annual subspecies, and ssp. *fallax* a year-long one as being able to establish a summer population. Generally, the genus *Cardamine* grows in winter and flowers in spring. The year-long annual growth habit of *C. flexuosa* ssp. *fallax* might be derived from winter annual.

In the present study, the experimental data and observations on the life history strategies of the genus *Cardamine* provide some further evidences for the general evolutionary trend from cross-pollinated perennial to self-pollinated annual breeding system in flowering plants.

Intraspecific differentiation of C. *flexuosa* in Japan and Nepal

The term “ecotype” was proposed for the ecological sub-unit of the product arising as a result of the genotypical response of an ecospecies to a particular habitat (Turesson 1922, 1925). The

ecotype is a basic biological entity. Its entity is adjusted to a range of habitats characterized by particular environments, e.g., annual fluctuations in climate, soil, other organisms and so on. The ecotypic differentiation is essentially physiologic-genetic (Clausen 1967; Armbruster 1985).

In widespread species, the ecogeographical differentiation is closely related to the size, migration, variation, selection, reproduction and isolation of populations (Ehrendorfer 1968; Barton and Charlesworth 1984). There are two extreme types of intraspecific differentiation: allopatric and partly sympatric patterns. The former pattern is found most typically in allogamous groups without restriction on intrapopulation gene flow, while the latter and more complex patterns are found in groups where intrapopulation gene flow is restricted (Ehrendorfer 1968; Kawano et al. 1971; Kawano 1974). The term "sympatric" differentiation has not been used to include such cases of differentiation on adjacent populations that are allopatric on the geographical criteria. Those adjacent populations are, therefore, described as parapatric (Jain and Bradshaw 1966).

The intraspecific differentiation of *C. flexuosa*, a widespread weed collected in Japan and Nepal, was compared morphologically, ecologically and genetically. It is interesting to compare the intraspecific differentiations occurring in Japan (the eastern border of Sino-Japanese Region) and in Nepal (near the western border of the Region).

In the present study six biotypes growing parapatrically in paddy fields, gardens and a stone wall in Japan and Nepal were detected (Kimata and Kobayashi 1996). Seventeen strains of *C. flexuosa* were used in the present study. Japanese strains were collected from five habitats: a garden, a stone wall, a roadside, a ditch and fallow paddy fields in three locations, Tokyo. Nepalese strains were collected from three habitats: a garden in a mountain area (Syangboche, about 4,000m alt.), two gardens, one in Ratna Park and another at a hotel, and a paddy field (Katmandu, about 1,300m alt.). These plant specimens were placed on file with the Herbarium of Tokyo Gakugei University.

Considerable differences in the intraspecific crossability observed among different combinations of biotypes indicate the occurrence of intraspecific differentiation among Japanese *C. flexuosa* strains. The intraspecific differentiation has already been suggested by several morphological and ecological characters, such as growing season, mode of seed dispersal, germination period, flowering period and others (Kimata 1983). The winter annual paddy field biotype can establish large populations only in the restricted habitats, such as the winter fallow paddy fields. On the other hand, the year-long annual garden biotype, which produces fewer seeds can establish small populations (a few plants per m^2) in rather wet microenvironments of various habitats, such as gardens, roadside and nurseries. Their F_1 hybrid has intermediate characters between the paddy field biotype and the garden biotype in Japan. Site 7 (a large population) is a parapatric habitat for both biotypes, and the plants growing here show wide variation in morphological and ecological characters, which suggests the occurrence of hybridization between these two biotypes.

Various patterns of phenotypic segregation of the six quantitative characters of Japanese F_2 hybrids and a comparison of ten characters between the paddy field biotype and the garden biotype clearly indicate the occurrence of intraspecific differentiation in *C. flexuosa*. The plant height of paddy field biotypes is taller than that of garden biotypes both in Japan and Nepal. However, on the six other characters (number of tillers, silique length, width of terminal leaflet, stem color, hairiness of stem and plant form), the variation patterns of Japanese biotypes show the opposite trend to those

of Nepalese biotypes. Therefore, the intraspecific differentiation of *C. flexuosa* in Japan did not occur in parallel with that in Nepal.

The intraspecific differentiation of *C. flexuosa* has occurred in many directions. According to the crossability among strains examined, the garden biotype is shown to be isolated sexually from the stone wall biotype, but not from the paddy field biotype in Japan. The garden biotype is considered to be isolated sexually from the paddy field biotype in Nepal because of the necrosis of F_1 hybrid seedlings. As F_1 hybrid seedlings become necrosis, the Japanese paddy field biotype is also considered to be isolated from the Nepalese paddy field biotype. As the other hand, the Japanese garden biotype is not considered to be isolated from the Nepalese garden biotype, which itself has not been isolated from the mountain biotype. As the results of crossings between the Japanese paddy field biotype and the Nepalese paddy field biotype, occurrence of sexual isolation among them is also indicated. The Japanese paddy field biotype is not very isolated, yet, from the Nepalese mountain biotype. Therefore, each garden biotype in Japan and Nepal is the prototype among six biotypes and can be called a garden "ecotype." Turesson (1922, 1925) defined the term "ecotype" as the product of the genotypical reaction of ecospecies to a particular, defined set of environment conditions. He also defined the sub-taxon "ecophene" as the reaction-type to a unique microenvironment.

Crossability among six strains of *C. flexuosa* from Japan and Nepal, and the seed germination rate and pollen fertility of F_1 hybrids.

Within a limited comparison of Japan and Nepal carried out in the present study, a model of intraspecific differentiation of *C. flexuosa*. The garden ecotype may be an original biotype because neither garden biotype is isolated for from the other. It is very interesting fact that there is no sexual isolation between the garden ecotype and the paddy field ecophene in Japan, but not between the garden ecotype and the paddy field ecotype in Nepal. As observed in other weeds growing in paddy fields (Sakamoto 1961; Matsumura 1967; Linhart 1974), the Japanese paddy field ecophene of *C. flexuosa* shows some phenotypic variation in various characters. This fact indicates a great diversity of intraspecific differentiation in *C. flexuosa* which may correlate with the period when rice cropping in paddy fields dispersed throughout Asia. The stone wall ecotype (83011) growing on a stone wall in Koganei, Tokyo is different morphologically, ecologically and genetically from the garden ecotype (83010). The Nepalese garden ecotype includes the mountain ecophene in Nepal. The intraspecific or ecotypic differentiation has occurred independently in Japan and Nepal. The intraspecific differentiation of *C. flexuosa* in the process adaptation to gardens, paddy fields stone wall and so on has occurred independently in Japan and Nepal. A model of intraspecific differentiation of *C. flexuosa* is proposed within a limited comparison in Japan and Nepal.

Comparative Studies on the Reproductive Systems of *Rorippa cantoniensis, R. islandica, R. dubia, R. indica* and *R. x brachyceras*, Cruciferae

The objective of this study on genus *Rorippa* was to make clear the life cycle and adaptive strategy by ecological genetics or evolutional biology. Mainly, it was the characteristics of a natural hybrid, *R. x brachyceras* (perennial, sterile) between *R. islandica* (annual) and *R. indica* (perennial).

Genus *Rorippa*, Cruciferae had dispersed 50 species in the world and 5 species in Japan. *R.*

islandica (Oeder) Boras grows in riverside, wetland, levee of paddy field, wheat field, orchard and so on in the warm temperate zoon from Hokkaido to Kyushu, Japan, and Canada, Australia, New Zealand. *R. indica* (L.) Hiern grows in field, levee, roadside, garden, etc., from Japan, Formosa, China, Korea, Malysia, to India. *R. cantoniensis* (Lour) Ohwi grows in riverside, wheat field, levee from Central Japan to South Korea, China, and Amur. *R. dubia* Hara grows in semi-shade place from Central Japan to South East Asia, South/North America. *R. x brachyceras* have been collected from some places in Japan. *R. sylvestris* (L) Besser have been collected from some sites of Hokkaido and Sugadaira, Ngano in Japan, and then from Finland, Denmark, Switzerland, Netherland, Canada, USA, and so on. *R. austriaca* (Crantz) Besser have collected at Sakura, Chiba (Victorin 1930, Jhon Wiley & Sons. Inc. 1979, etc.).

R. cantoniensis and *R. islandica* are considered to be self-pollinated annual species and *R. dubia* and *R. indica*, self-pollinated perennial species. *R. x brachyceras* seems to be a hybrid between *R. islandica* and *R. indica* (Kitamura, 19). This natural hybrid and artificial hybrids sterile perennial plants. One strain of *R. sylvestris* grown in Nagano is a cross-pollinated perennial, but another grown in Hokkaido is a sterile perennial (Nakatani and Kimata, 1993).

Stebbins (1950, 1957, 1958) recognized that annual species are predominantly self-fertilized in spite of the great diversity in the reproductive systems, while perennials are cross-fertilized in Gramineae and Compositae. This trend may be generally admitted, including the cases of *Mazus*, Scrophurareaceae (Kimata, 1978), and *Cardamine*, Cruciferae (Kimata, 1983; Kimata and Kobayashi, 1996). However, there are many exceptions and compromised systems such as the case of *Rorippa*, Cruciferae, in the present study. The self-pollinated annual species are often the best colonizers in disturbed habitats, because massive seed production in the early stage of the colonizing process plays an important role in the establishment of new populations (Stebbins, 1958; Ehrendorfer, 1965; Antnovics, 1968; Lefebvre, 1970).

In this case, of course, *R. cantoniensis* and *R. islandica* are excellent annual colonizers by means of numerous small seeds, and also two self-pollinated perennials of *R. dubia* and *R. indica* are better colonizers with large seed production. *R. dubia* and *R. indica* have not only certain possibilities of vegetative propagation by means of root segments but also hopeful possibilities by stem segments, when they are cut for physical weeding in shady gardens and roadsides. *R. x brachyceras* and F_1 hybrids can maintain themselves with the perenniality and vegetative reproduction, in spite of their sterility. Even if *R. islandica* is an annual species, it has large potentiality of vegetative reproduction in a moist field as cutting it for weeding at the juvenile stage. Moreover, *R. sylvestris* is cross-pollinated or sterile perennial species but a better colonizer too with vigorous vegetative reproduction (Figure 9), Nakatani and Kimata, 1993).

Figure 9. Weeds of genus *Rorippa*

a, *R. islandica*; b, *R. dubia*; c, *R. cantoniensis*; d, *R. sylvestris*; e, *R. indica*.

R. islandica and *R. indica* seem to cross easily each other in sympatric populations such as paddy fields (Figure 1) and make an interspecific hybrid, *R. x brachyceras*, because their artificial cross-abilities are often very high and F1 hybrids resemble *R. x brachyceras* in the morphological and ecogenetical characteristics. The F_1 hybrid of *R. indica* x *R. islandica* shows a heterosis of vigorous growth with high seed germination rate and maintains itself with perenniality and vegetative reproduction (Kimata and Shibata, unpublished). On the contrary, the reciprocal F_1 hybrid shows weak growth with low seed germination rate. Both F_1 hybrids do not produce any seeds at least through the pollen sterility and F_2 hybrids never grow. *R. islandica* and *R. indica* have same chromosome number, 2n= 16 and 8 bivalents in meiosis, while *R. x brachyceras* and their F_1 hybrids have 16 monovalents. Both species differ in their cytological genomes. *R. islandica* has already reported the chromosome number, 2n = 16 (2x) and 32 (4x) (hybridization).

The B_1 and B_2 hybrids show well growth when the F_1 of *R. indica* x *R. islandica* and then its B_1 were repeatedly backcrossed by *R. indica*. The introgression between *R. islandica* and *R. indica* seems to be possible theoretically, but it has not been observed in natural populations yet. These Japanese interspecific F_1 hybrids do not accept any pollens of *R. islandica*, but Nepalese interspecific F_1 hybrids accept the pollens of both *R. islandica* and *R. indica*. Therefore, it seems to be more or less possible that the introgressive hybridization occurs in natural populations of Nepal. Additionally, *R. islandica* does not make a sexual barrier between Japanese strain and Nepalese, while *R. indica* has made a sexual barrier each other.

R. islandica is an annual, while *R. indica* is a strict perennial. *R. x brachyceras* and most of their interspecific F1 hybrids are perennials. These facts indicate clearly that perenniality is a dominant against annuality. However, two F_1 hybrids derived from Japanese *R. islandica* as a female strain show rather weaker perenniality. It needs more detail investigation that the intraspecific F_1

hybrid between Japanese strain and Nepalese of *R. islandica* shows weak perenniality too. This trait may be concerned with the potentiality of vegetative reproduction in *R. islandica* at the juvenile stage.

R. indica has more attractive nectar contents and bigger yellow flowers for pollinators such as bees than *R. islandica*. The pollinators ensure their feed by much volume and high quality of the nectar and the even a little bigger yellow flower is a good sign for inducing pollinators to out-cross in *R. indica* such as out-crossed perennial. The other self-pollinated species do not need to make them. Actually, *R. indica* gets more visits from pollinators than *R. islandica*, and also does the second visit after pollinators visit first *R. islandica*. Moreover, *R. x brachyceras* is always growing around plants of *R. indica* in natural populations. The similar hybridization of genus *Rorippa* has often been observed in Europe (Howard, 1947; Mulligan and Porsild, 1968). It comes to the conclusion that most plants of *R. x brachyceras* are F_1 hybrid plants derived from *R. indica* x *R. islandica*.

R. indica has more attractive nectar contained a large quantity of sugars and amino acids and bigger yellow flowers for pollinators and gets more visits from them than *R. islandica*. *R. islandica* (2n = 16) and *R. indica* (2n = 32) cross easily each other in natural habitats and make their interspecific hybrids. Artificial F_1 hybrid (2X = 24) of *R. indica* x *R. islandica* resembles *R. x brachyceras* (2X = 24) in the morphological and ecogenetical characteristics. These hybrids are sterile perennials but show a heterosis growing well and maintain themselves with vegetative reproduction. Therefore, *R. x brachyceras* is derived from the F_1 hybrid of *R. indica x R. islandica*. The self-pollination rate, calculated from the bagged inflorescences of *R. cantoniensis, R. islandica, R. dubia* and *R. indica* was 98.1-100 % as shown in Table 4. The pollen fertility of these four species was 87.4-96.2 %, but that of *R. x brachyceras* was only 2.5 % as shown in Table 5. The fructification rate of four species, assessed from open-pollinated inflorescences, was 95.3-100 %, but that of *R. x brachyceras* was nil. These data indicate that *R. cantoniensis, R. islandica, R. dubia* and *R. indica* are all self-pollinated species. However, only *R. x brachyceras* is sterile. The petal length was around 1 mm in *R. cantoniensis* and *R. islandica*, ca. 2.2 mm in *R. x brachyceras* and 3.5 mm in *R. indica*. *R. dubia* had not any petal, but attached one or two petals at an irregular case. Usually, these species have four yellow petals.

The number of siliques per plant was ca. 380 in *R. cantoniensis*, 690 in *R. islandica*, 230 in *R. dubia*, 130 in *R. indica* and 1050 in *R. x brachyceras*, respectively as shown in Table 8. The number of seeds per silique was ca. 206 in *R. cantoniensis*, 45.8 in *R. islandica*, 74.0 in *R. dubia*, 79.3 in *R. indica* and nil in *R. x brachyceras*, respectively. A plant of *R. cantoniensis* produced ca. 77,900 seeds by means of many tillers. A plant of *R. islandica* produced ca. 30,000 seeds. A plant of *R. dubia* produced ca. 16,000 seeds. A plant of *R. indica* produced ca. 9,600 seeds, with a few main inflorescences by a few tillers. On the other hand, a plant of *R. cantniensis* produced ca. 77,000. Of course, *R. x brachyceras* did not produce any seeds. The seed weight of *R. indica* (64.1 mg/1,000 seeds) was almost the same weight of *R. dubia* (61.5 mg/1,000 seeds), a little heavier than that of *R. islandica* (50.9 mg/1,000 seeds), and two and half times that of *R. cantoniensis* (26.8 mg/1,000 seeds).

Table 8. Fructification rate from open pollination and seed production in genus *Rorippa*

	R. cantoniensis	*R. islandica*	*R. dubia*	*R. indica*	*R. x brachyceras*
Fructification rate (%)	100	95.3	95.8	96.3	0
Pollen fertility (%)	87.4	92	94.3	96.2	2.5
Siliques per plant	377.8	686.5	227.1	126	1051.7
Seeds per silique	205.7	45.8	74	79.3	0
1,000 seeds weight (mg)	26.8	50.9	61.5	64.1	-
Seeds per plant 1)	77,714	29,964	16,100	9,622	0

1) Seeds per plant = Siliques per plant x Seeds per silique x Fructification rate

Figure 10. *R. sylvestris* (a) and the sprouting from roots (b) in Hokkaido

The reproductive systems of *Rorippa cantoniensis, R. islandica, R. dubia,* R. x brachyceras (a natural hybrid) and an artificial hybrid between *R. indica* and *R. islandica* were compared. *R. cantoniensis* and *R. islandica* are self-pollinated annuals, while *R. dubia* and *R. indica* are self-pollinated perennials. These four species produce a great many seeds, but the both perennial hybrids do not produce any seeds because of the sterility. *R. islandica*, *R. dubia*, *R. indica* and two hybrids have large potencialities of vegetative reproduction by means of root and stem segments. *R. indica* and *R. islandica* may cross each other and make an interspecific hybrid, *R. x brachyceras*. The reproductive systems of weedy *Rorippa* species may indicated each characteristic in the colonizing strategy into their habitats (Figure 10, Figure 11, Figure 12).

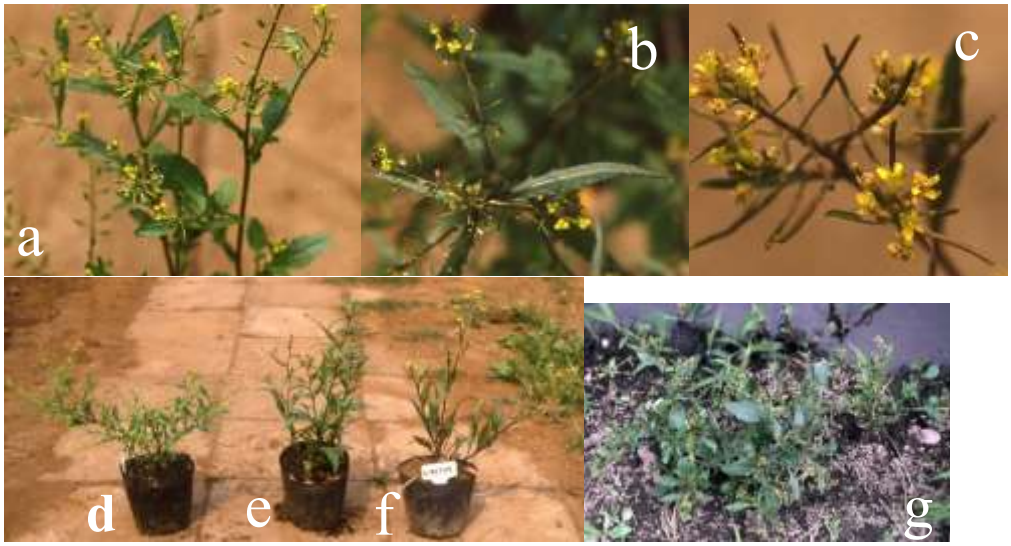


Figure 11. *R. x brachyceras*: an artificial hybrid between *R. islandica* and *R. indica*

a, *R. islandica* (annual); b, a hybrid F_1 (perennial, sterile); c, *R. indica* (perennial);

d, *R. islandica*; e, F_1 hybrid; f, *R. indica*; g, natural hybrid *R. x brachyceras* (perennial, sterile).

R. cantoniensis is a winter annual grown mainly in fallow paddy fields, while *R. islandica* is a year-long annual not only grown in and around paddy fields but also colonized aggressively into moist upland fields. *R. dubia* is a perennial grown in gardens and along roadsides, while *R. indica* is a perennial not only grown in gardens and along roadsides but also colonized aggressively into upland and paddy fields. *R. cantoniensis* and *R. dubia* germinated in autumn and flowered in the next spring. On the one hand, *R. islandica* and *R. indica* germinated twice mainly in autumn and in the next early summer after its fruiting. *R. islandica* flowered twice mainly in April-May and seldom in July-August. Also, *R. indica* flowered twice mainly in May-June and sometimes in August-September. *R. islandica* often grows together with *R. indica* in and around paddy fields (Table 9). These two species may cross each other during the flowering period overlapped in May and make an interspecific hybrid plant, *R. x brachyceras*. This hybrid plant is a sterile perennial but maintains itself by means of vegetative reproduction. The reproductive systems of weedy *Rorippa* species may indicate each characteristic in the colonizing strategy into their habitats.

Table 9. Life cycle of weedy *Rorippa* species

Species	Sprinng	Flowering season	Summer	Autamun	Winter	Growth habit
R. islandica	rosette, bolting	flowering, fructification		germination	rozett	yearlong annual
Cold region		germination, growing, flowering, fructification				summer annual
R. indica	rosette, bolting	flowering, fructification, dormancy		germination, budding	rozett	perennial
R. x brachyceras	rosette, bolting	flowering, sterile	stock dormancy	budding	rozett	perennial
R. cantoniensis	rosette, bolting	flowering, fructification, dormancy		germination	rozett	winter annual
R. sylvestris	rosette, bolting	flowering, fructification, dormancy		germination, budding	rozett	perennial
Hokkaido	rosette, bolting	flowering (sterile)	dormancy, budding from stock and roots		rozett	perennial

The natural habitats of *R. cantoniensis* and *R. islandica* are restricted mostly to fallow paddy fields and levees but sometimes the latter invades into upland fields. *R. dubia* grows in shady gardens, along roadsides and levees of upland field. The habitat of *R. indica* is found widely in levees of paddy and upland fields, gardens and along roadsides. Moreover, this species often invades into paddy fields and upland fields. *R. x brachyceras* is found in paddy fields and levees sometimes. *R. cantoniensis, R. islandica* and *R. indica* grow sympatrically in fallow paddy fields, while *R. dubia* grows in a garden together with *R. indica*. *R. cantoniensis* was a winter annual observed only from autumn to next spring. *R. islandica* was a year-long annual observed in both winter and summer, but the summer population was small on the levees of paddy field in Tokyo. *R. dubia* and *R. indica* were observed in all seasons.

The stems of *R. cantoniensis, R. islandica, R. dubia, R. indica* and a F1 hybrid were cut into about 10 mm length and 2-mm diameter segments, each with one leaf. Also, their roots were cut into about 10 mm length and 3-mm diameter segments. The cuttings (over 28 segments per species) were grown on wet papers in Petri dish under 23 C constant and about 1,000 lux continuous light. After two weeks, the rooting from stem segments and the sprouting from root segments were observed.

The rooting rate from stem segments and the sprouting rate from root segments of *R. cantoniensis* were both nil. The rooting rate from stem segments was 52.4 % in *R. islandica*, 16.0 % in *R. dubia*, 8.5 % in *R. indica* and 50.0 % in F1 hybrid between *R. indica* and *R. islandica*. These stem segments showed well shooting rates ranging from 54.9 % to 91.2 % and vigorous growth too. The sprouting rate from root segments was 78.0 % in *R. islandica*, 91.2 % in *R. dubia*, 99.4 % in R. indica and 100 % in F_1 hybrid between *R. indica* and *R. islandica*. Those shoots of root segments grew vigorously and showed well rooting rates ranging from 62.0 % to 100 %. These data clearly indicate that *R. cantoniensis* does not propagate with any vegetative reproduction, while the others have large potentiality of vegetative reproduction by means of root segments (Table 10). Moreover, *R. islandica* and F1 hybrid between *R. indica* and *R. islandica* may also propagate with rooting and shooting from stem segments, when they are cut for weeding in a moist fallow paddy field.

Table 10. Sprouting from buds and stem segments of genus *Rorippa*

	R. islandica		*R. indica*		Artifitial F1	*R. dubia*	*R. cantniensis*
No. of root segments	44	106	59	101	113	34	28
No. of sprouting segments	2.9	2.1	4.1	2.4	3.3	3.9	0
The longest bud mm	9.0	5.4	22.7	25.5	30.4	7.7	0
Sprouting %	68.2	82.1	100	99.0	100	91.2	0
Greening %	61.3	73.6	100	99.0	100	82.4	0
Rooting %	70.5	58.5	100	95.0	100	91.2	0
No. of stem sections	42	105	45	108	96	75	30
No. of roots	5.2	0.8	0.1	0.1	1.1	0.3	0
The longest root mm	12.1	4.2	0.5	0.3	2.2	1.8	0
Rooting %	76.2	42.9	11.1	7.4	50.0	16	0
Browning %	9.5	1.0	0	0	2.1	0	100
Sprouting %	92.9	90.5	100	36.1	70.8	86.7	0
The longest shoot mm	21.6	11.0	29.2	7.2	17.8	8.1	0

Natural populations of *R. islandica*, *R. indica* and *R. x brachyceras* in/ around rice fallow paddy fields (a and b) observed. At the field (a), the number attached to the triangles and quadrats shows the number of plants. At the field (b), the black bars show the number of small silique form and the white circles show large silique form of *R. islandica*. The black triangles show *R. indica* and the white triangles show *R. x brachyceras*, as illustrated with Figure 12.

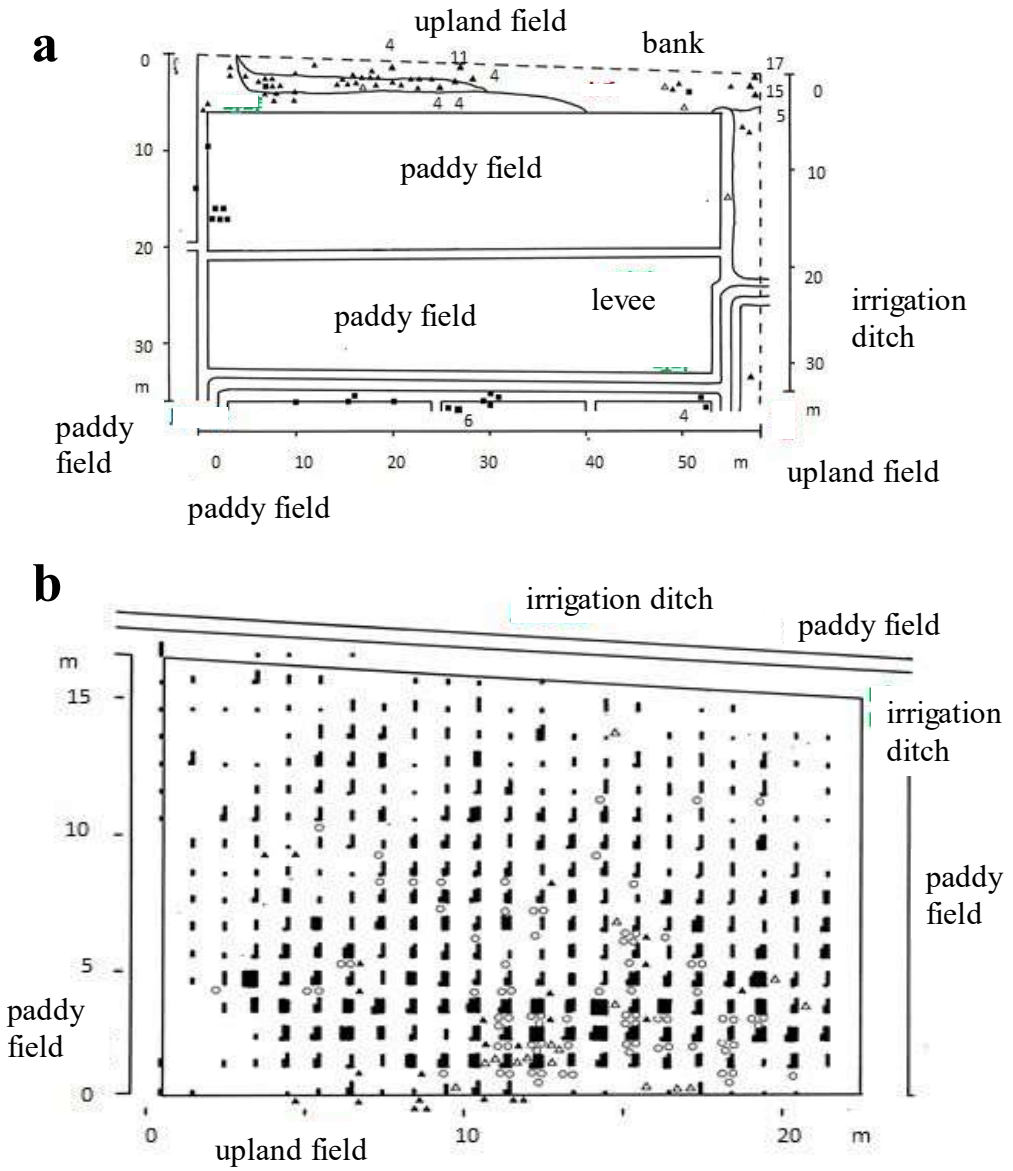


Figure 12. Distribution of *R. islandica*, *R. indica* and their hybrid around rice paddy fields

a, ■ *R. islandica*; ▲ *R. indica*; △ *R. x brachyceras*. b, ▌ *R. islandica*/ plants per m^2.

AFLP markers

DNA extraction was performed on young leaf tissue ground in liquid nitrogen and incubated in 1.5-ml tubes containing 0.5 ml of buffer A for 10 min at 60 °C by using CTAB (hexadecyl-trimethyl-ammonium bromide) methods (Murray and Thompson 1980). The AFLP procedure was performed according to Applied Biosystems (2005), Bai et al. (1999), and Suyama (2001) with some modifications. Amplification reactions were performed according to the same protocol. Five primers associated with *Eco*RI (E+AAC, E+AAG, E+AGG, E+ACT, and E+ACA) were used in combination with 5 primers associated with *Mse*I (M+CAG, M+CTG, M+CTA, M+CAT, and M+CAA). Five microliters of amplification products were loaded onto a 5.75% denaturing polyacrylamide gel (LONZA) and electrophoresed in 1× TBE for 1 h. Bands were detected using the silver staining

protocol described by Cho et al. (1996). The bands were detected on the gel at the finest level of sensitivity by Lane Analyzer (ATTO), the raw data were adjusted, and then the visible and reproducible bands were scored for accessions as present (1) or absent (0). The dendrogram of the AFLP markers was constructed using the neighbor-joining and UPGMA methods (Nei and Kumar 2000) with the bootstrap analysis (PAUP* ver. 4.0) and the hierarchical cluster analysis (group average method, SPSS ver. 21) on all data matrices of materials used as shown in Figure 13. AFLP dendrogram shows a very clear phylogenetic tree. Therefore, *R. x brachyceras* is the natural hybrid between *R.islandica* and *R. indica*.

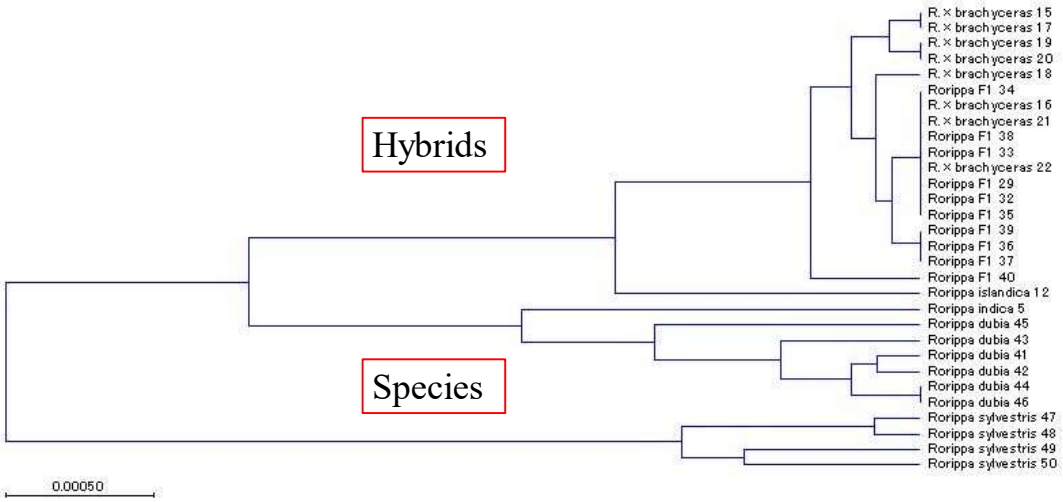


Figure 13. AFLP dendrogram of *Rorippa* by UPGMA

Chapter 3 Evolution of the Poaceae

The grass family is not the largest in terms of species and genera, coming after Compositae and so on, but its importance is beyond doubt for it provides the grasslands which occupy a third of land's surface, and the cereal crops upon which much of the world's population depends for its food. The grasses are a successful family, in which three themes constantly recur: their adaptability to changeable environments; their ability to coexist with grazing herbivores an with man; and their possession of a distinctive lifeform. The life cycle of most grasses is strongly seasonal. Perennials become dominant when the season is averse to grow. Annuals overwinter as seed, a strategy generally regarded as more advanced because of the high standard of reproductive efficiency required (Clayton and Renvoize 1986).

Chapman (1996) have written an excellent introduction on Poaceae as follows. Both Poaceae (rice order) and Cyperaceae had differentiated from Commelinales. The Poaceae contains about 10,000 spices. Long before *Homo sapiens* became conspicuous, grasses had and were evolving their distinctive features. Grasses have linear leaves and small green flowers. Thise are generally drought tolerant. The features just outlined combine to fit grasses for open habitats so that they tend to occur as pioneer or early colonists. A perennial grass is well adapted to vegetative reproduction. As with many other angiosperms, grasses demonstrate the evolution of annual or ephemeral forms from perennial forebears, and here the changeover is an interesting one.

Many annuals, wheat and barley among them, retain tillering ability and a tiller with its adventitious roots can be separated from the mother plant and propagated independently. What conditions annualism is a massive commitment to seed production, sufficient to senesce the plant. The situation is irreversible and genes from *Agropyron* introduced into wheat can create a perennial habit. The emergence of C4 photosynthesis seems likely to be due to dearth of CO_2 in Tertiary atmospheres. The dawn of agriculture meant not only that preferred plants were recognized but, additionally, others were brought into cultivation. Since weeds survive independently of having to be planted and only fed and watered incidentally, they create an impediment to agriculture.

The Poaceae are anemophilous, which have grown under the various environment. The Poaceae had dispersed widely to the whole earth (Hotta 1974, Tamura 1974).

Growth Habit and Growth Pattern of C*oix lacryma-jobi* var. *ma-yuen* and var. *lacryma-jobi*, Poaceae

In the present study, the differences between the ecogenetical characters on the growth habit and growth pattern of an ecogenetically annual cultivated variety, C*oix lacryma-jobi* var. *ma-yuen* (Sakamoto et al., 1980), and its closely related wild perennial, C*oix lacryma-jobi* var. *ma-yuen* has been recognized as a domesticated annual species by taxonomists (Makino 1948; Ohwi 1953), but both var. *lacryma-jobi* is a wild perennial. The relation between growth habit and growth pattern of those two varieties were compared. C*oix lacryma-jobi* var. *lacryma-jobi*, Gramineae, are compared

in order to elucidate some experimental evidences to the problem of intraspecific differentiation from perennial form to ecologically annual one.

Two varieties of C*oix lacryma-jobi* L. var. *ma-yuen* and var. *lacryma-jobi,* two F_1 and one F_2 hybrid strains were used in this study. C. *lacryma-jobi* L. var. *lacryma-jobi* (strain no. 76501) is a wild variety collected in Kamakura-shi, Kanagawa Prefecture in 1975. C. *lacryma-jobi* var. *ma-yuen* (Roman.) Stapf is a domesticated variety (strain no. 76505) obtained from the Agricultural Station of Toyama Prefecture in 1975. These two varieties were crossed reciprocally in 1975 (crossability ca. 60-70%) and obtained two F_1 hybrid strains, i.e., 76506 (76501 x 76505) and 76508-1 (76505 x 76501). An F_2 progeny (76508-2) was obtained from 76508-1 which was isolated from the other strains in 1976 in order to avoid pollination by alien pollen grains.

Many floristic workers described that C. *lacryma-jobi* L. var. *lacryma-jobi was* a perennial plant but var. *ma-yuen was* an annual one (e.g., Makino 1948; Ohwi 1953). All plants of C. *lacryma-jobi* L. var. *lacryma-jobi* and 22.2-88.9% of var. *ma-yuen* survived in the growth cabinets. Under the upland field plot the survival rate of var. *lacryma-jobi* was 80% in 1976 and 16.7% in 1977. Var. *ma-yuen* did not survive in 1976 and 1977. In F_1 strains none of 76506 survived, but 16.7% of 76508-1 did. The two varieties died under lower temperature (frost, under C and D plots in Table 30) or higher temperature (dryness, under A plot). Murakami and Harada (1958) observed that 20% of var. *ma-yuen* and all of var. *lacryma-jobi* and their F_1 strains survived in next growing season under upland field in Kyoto. The survival rate of F_2 was ca. 80% (Murakami 1961) in Kyoto and 61% in Tokyo in the present study. Moreover, two strains of var. *ma-yuen* collected from North Halmahera, Indonesia in 1976, have been vegetatively maintained in an unheated greenhouse during at least three years (Sakamoto et al., 1980). Judging from these observations, it is concluded that *C. lacryma-jobi* var. *lacryma-jobi* is perennial plant, while var. *ma-yuen* is a potentially perennial but ecologically annual plant having weak cold resistance.

The grain of var. *ma-yuen* germinated more rapidly than that of var. *lacryma-jobi*. The grain germinating pattern of F_1 was intermediate between the two parents as shown in Fig. 18 and the pattern of F_2 showed the same pattern as var. *ma-yuen* parent as shown in Fig. 19. The rapid grain germination of var. *ma-yuen* as well as F_2 indicates one of the characteristics of annual plants.

The plants height of var. *ma-yuen* increased more rapidly than that of var. *lacryma-jobi*. Similarly, the number of tillers of var. *ma-yuen* increased and reached a plateau more rapidly than that of var. *lacryma-jobi*. Therefore, it is thought that the former variety indicates annual growth pattern, while the latter shows perennial one. The growth pattern of F_1 was intermediate between the two parents. The frequency distribution of plant height of F_2 showed a bimodal curve as shown in Fig. 21. One peak corresponds with the mean plant height of var. *ma-yuen* parent and the other showed transgressive segregation as observed by Murakami (1961). The frequency distribution of the number of tillers of F_2 showed a normal curve as shown in Fig. 23. The peak is in accordance approximately with the mean number of tillers of var. *ma-yuen*. Therefore, the large part of F_2 plants shows vigorous growth with small tillering capacity.

The heading date of var. *ma-yuen* was earlier than that of var. *lacryima-jobi* as shown in Table 30 and 31, and Fig. 20. The early maturity of var. *ma-yuen* is one characteristic displayed by annual plants, while the late maturity of var. *lacryma-jobi* is one of perennial characteristics. The heading date of F_1 was intermediate between the two parents. The frequency distribution of heading date of

F_2 showed a bimodal curve. The earlier half part of the curve coincides with that of var. *ma-yuen,* while the latter half part of agrees with the late heading of var. *lacryma-jobi*. Murakami (1961) presumed that the frequency distribution of heading date in F_2 was similar to that of trihybrid (segregation ratio 10:54 = early var. *ma-yuen* type: late var. *lacryma-jobi* type). In the present study, however, the segregation ratio (4:5) did not agree with the above ratio. Moreover, the heading date of two parents was later and the difference of heading date between two parents was less remarkable in this study than in Murakami's data. The variation of heading date, therefore, needs to be reexamined.

The pollen fertility is higher and the protogyny is lower in var. *ma-yuen* than in var. *lacryma-jobi* (Tables 32 and 33). Therefore, the grain fertility of var. *ma-yuen* is higher than that of var. *lacryma-jobi* (Table 32). Moreover, var. *ma-yuen* sets more grains than var. *lacryma-jobi*, but grains were lighter than that of var. *lacryma-jobi* (Table 34). Murakami et al. (1960) reported weak sexual isolation between those two varieties. The same can be said from the pollen and grain fertility of F_1 shown in this experiment also.

The proportional distribution of dry matter into the inflorescences and grains attained ca. 11% (9.1g) of the total plant dry weight in var. *lacryma-jobi* and 20% in var. *ma-yuen* in the end of growing period (Fig. 25). Kawano and Hayashi (1977) reported that the reproductive allocation into grains attained 41.0% (the highest rate) in var. *ma-yuen*. The distribution into the subterranean stems attained 6% (5.0g) in var. *lacryma-jobi* and 2% (0.9g) I var. *ma-yuen* at the end of growing period. Var. *lacryma-jobi* allocates half as much energy for sexual reproduction and three times as much into vegetative one as var. *ma-yuen* does. Also, these characteristics on the reproductive systems suggest that var. *ma-yuen* is an annual form and var. *lacryma-jobi* a perennial one (cf. Kawano 1975).

McNaughton (1975) described that populations of *Typha* in short growing season produced many small rhizomes, since such populations were subject to high rhizome mortality in winter time. *C. lacryma-jobi* var. *lacryma-jobi* produced more tillers with dormant buds and more ratoons from cutting stump than var. *ma-yuen* as shown in Tables 35 and 36. However, there are no correlation between total number of tillers and the number of sprouting tillers wintered or the survival rate. There is a significant but low positive correlation between the number of non-productive tillers and the number of sprouting tillers wintered. Accordingly, there is not very close relation between the tillering capacity and the wintering habit in *Coix*. In order to shed more light on this problem, further physiological and genetical investigations on wintering habit are needed.

Oka and Morishima (1967) observed that the culm segment in perennial strains of *Oryza* rooted more easily than in annual one. It is thought that the rooting from culm is related to the degree of vegetative reproduction. In two varieties of *C. lacryma-jobi* the rooting and sprouting rates from culm segments were rather high, and not significantly different between them. This observation suggests that var. *ma-yuen* is a potentially perennial plant.

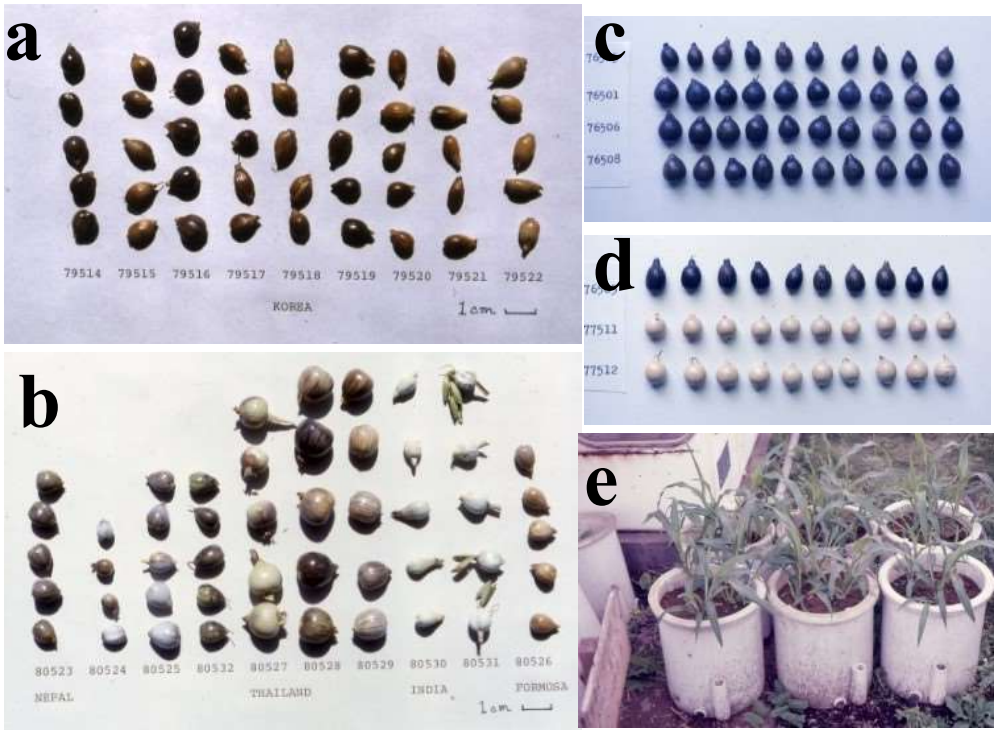


Figure 14. Morphological variation of bract sheath in *Coix lacryma-jobi*
a,b,c,d, bract sheath; e, var. *ma-yuen* (upper) and var. *lacryma-jobi* (below)

Judging from the present results obtained from the comparative studies on growth pattern, reproductive systems and tillering capacity of these two varieties, it is concluded that *C. lacryma-jobi* var. *ma-yuen* is an ecologically annual but potentially perennial plant and var. *lacryma-jobi* is apparently a perennial one as summarized in Table 10.

Table 10. Characteristics of *Coix lacryma-jobi* var. *lacryma-jobi* and *C. lacryma-jobi* var. *ma-yuen*

Characteristics	var. *lacryma-jobi*	var. *ma-yuen*
Breeding system	high degree of protogyny	protogyny
Grains per plant	ca. 80	ca. 270
Asexual reproduction by rhizome	present	absent
Germination	gradual, late	simultaneous, earlier
Heading date	late	early
Growth habit	perennial	ecologocal annual
Habitat	creek, roadside, river side	upland field

Growth habit of genus *Zea*

Zea mays (maize, annual), teosinte (Figure 15) and *Tripsacum* are the three New World members of the tribe Maydeae. Teosinte (2n=20), a weedy annual, is a close relative of maize (2n=20). Maze and teosinte differ most in the structure of their female inflorescences and in their chromosome knob patterns. Morphologically teosinte plants often resemble maize. The teosinte

spike is very loosely enclosed by a few husks, the rachis of the spike becoming very fragile upon maturity, and the fruit case disseminating easily as shown Figure 15. Maize, with neither natural seed dispersal nor seed dormancy, is wholly dependent upon man for its propagation (Goodman 1995).

The oriental Maydeae (*Coix* and so on) are usually acknowledged to be but distantly related to maize (Mangelsdorf 1974), although there has been occasional speculation that *Coix*, which has knobbed chromosomes in multiples of x=5, is more closely related to maize than the other oriental genera.

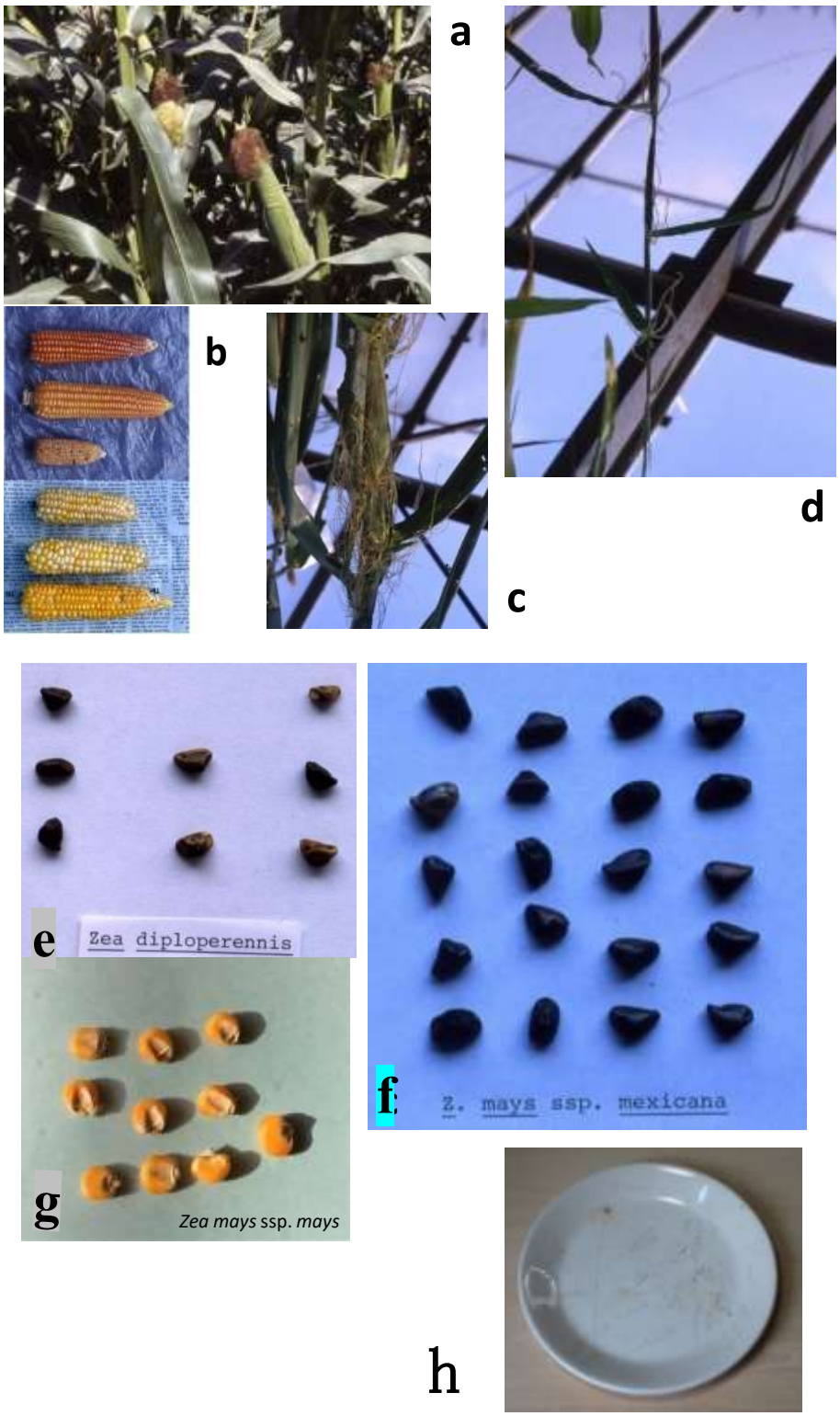


Figure 15. Ears and seeds of genus *Zea*

a, ears of *Zea mays* from Uzbekistan; b, ears of *Z. mays* from Nepal; c, ear of *Z. mays* ssp. *mexicana*; d, ear of *Z. diploperennis* ; e, seeds of *Z. diploperennis*; f, seeds of *Z. mays* ssp. *mexicana*; g, seeds of *Z. mays* ssp. *mays* from Yamanashi, Japan ; h, *Z. diploperennis* illustrated by Iltis (1983).

Guzman came on a large stand of grass and sent seeds to Iltis (1983, 1987; Fussell 1992). Iltis found that the grown plants had the same number of chromosomes as maize, and that Guzman had

discovered a new species, which Iltis labeled *Zea diploperennis*, or perennial teosinte. Iltis had sent me the seeds (Figure 15d, e).

I had participated in the US-Japan Science Seminar, New York Botanical Garden in 1983. At this time, I had directly heard the story of maize evolution from Iltis, and then he had sent me the seeds of *Zea diploperennis*.

Differentiation of ecotype on genus *Agropyron*, Poaceae

The early ecotype (annual) of *Agropyron tsukushiense* (Honda) Ohwi var. *transiens* (Hack.) Ohwi adapted to fallow paddy fields are ecologically and genetically differentiated from the common type commonly found on roadsides, levees and other disturbed habitats (Sakamoto 1961). The closely related *A. humidorum* Ohwi et Sakamoto grows in fallow rice paddy fields, often sympatrically found with the early ecotype of *A. tsukushiense* var. *transiens* (Ohwi and Sakamoto 1964; Sakamoto 1978). Therefore, the relation between growth habit and habitat of those two species was studied.

Field observation

Four winter fallow paddy fields, designated P-1, P-2, P-3 and P-4, were selected in the suburbs of Mishima-shi, Shizuoka Prefecture. In P-1 a mixed swarm of the early ecotype of *A. tsukushiense* var. *transiens* and *A. humidorum* were found. In P-2 the former was abundant but the latter species rare, while in P-3 the reverse situation was observed. In P-4 the latter species was abundantly grown but the former was very seldom found. The number of seedlings formed by seed and propagules produced from culm segment were counted by $1m^2$ quadrat method in a fallow paddy field (P-1) on November 21st, 1975 and November 22nd, 1976. At the same time, 10cm soil surface of the paddy field was dug in order to measure the depth of soil from where seedlings and sprouting propagules are found.

The number of germinating seeds and the number of sprouting or non-sprouting segments found in soil clods (50 cm length x 50 cm width x 10 cm depth = 0.025 m^3) in two fallow paddy fields (P-2 and P-3) were counted on January 16th, 1978. Such soil clods were sampled randomly at 3-5 sites in a paddy field. The relationship between the number of nodes of culm segments and their sprouting rate of *A. humidorum* was examined using same methods in a paddy field (P-4).

Seed germination and sprouting of culm segment under several conditions:

Three used strains were collected and observed in Mishima-shi, Shizuoka Prefecture. The seeds used were stored under three different water conditions, i.e., upland, lowland and dry conditions, and they were kept under five different temperature conditions, i.e., 1) daytime 35 C, nighttime 25 C; 2) daytime 25C, nighttime 15C; 3) 20 C constant, 4) 6 C constant; and 5) natural temperature conditions in 1976. The experiment consists of 14 water and temperature condition plots. Under the upland condition, seeds were packed into nylon-net bag and then stored in the loam soil which was watered at intervals of several days. Under the lowland condition, they were stored in the submerged loam soil. Under the dry condition, they were stored in the sealed can containing silica gel. At the interval of 15 days stored seeds were taken out from those experimental plots and used for the germination tests. The germination tests were conducted with the unglazed germination plates

under the conditions light unglazed germination plates under the conditions light 8,000 lux and 25 C constant.

The culm segments having one node were stored under the upland and lowland conditions and they were kept under four different temperature conditions, i.e., 1) daytime 35 C, nighttime 25 C; 2) daytime 25 C, nighttime 15 C; 3) 20 C constant; 4) natural temperature conditions, in 1975 and 1976. Therefore, the experiment consists of eight water and temperature condition plots. At the interval of 15 days 30 stored culm segments were taken out from each plot and used for the sprouting test. The sprouting test was carried out on the wet filter paper in Petri dish under continuous light 8,000 lux and 25 C constant.

According to Sakamoto (1978), the natural life cycle of the early ecotype of *A. tsukushiense* and *A. humidrum* shows characteristics of a typical weed in winter fallow paddy fields. At around the maturation stage of those two species, the preparation of rice cultivation is started. During this practice seeds and culms or stumps of those species are dispersed uniformly in the soil of the paddy field. During rice cultivation in summer, they were preserved in dormant state. In the middle of September seeds and propagules start to germinate or sprout and young plants are in tillering stage when rice plants are harvested in October- November. Therefore, these two species are temporally segregated their habitat from rice plants. They grow often sympatrically and they have adapted very successfully to winter fallow paddy fields. However, in the present study a remarkable difference as to the mode of reproduction was recognized between these two species. As shown in Table 38, 39 and 40, in natural habitats the clone of early ecotype usually dies within a year and reproduces only sexually by seeds. So, it is just like an annual plant in spite of perennial under upland condition. Therefore, this ecotype is defined as an ecologically annual but potentially perennial species. On the other hand, *A. humidorum* reproduces both sexually by seeds and asexually by propagules produced from culms.

Compared with the common type, the early ecotype and *A. humidorum* show clearly the adaptability to paddy fields. For example, seeds of those species are maintaining the germinating ability in D plot (natural temperature under lowland condition). According to Ohwi and Sakamoto (1964), adaptation to moist environment is one of the most pronounced characteristics of *A. humidorum*. There have been observed two distinct characters of this species which imply high adaptiveness to the habitat of winter fallow paddy field. One is the formation of an abscission layer at maturity on the node below the flag leaf. Thus, from this node on upward the spike is easily removed from the rest of plant by wind or other physical forces. The other is the perennialization of culm with the exception of the upper most internode and spike. New shoots and roots are produced very easily from the nodes when the condition is favorable.

As was shown clearly in this experiment (figs. 27 and 28) dormancy of seeds and culm segments from June to September under lowland condition is also additional adaptive character of this species. Judging from those observations, it is concluded that *A. humidorum* has more positive adaptation to propagate vegetatively by perennialized culms or clones than to reproduce sexually by seeds.

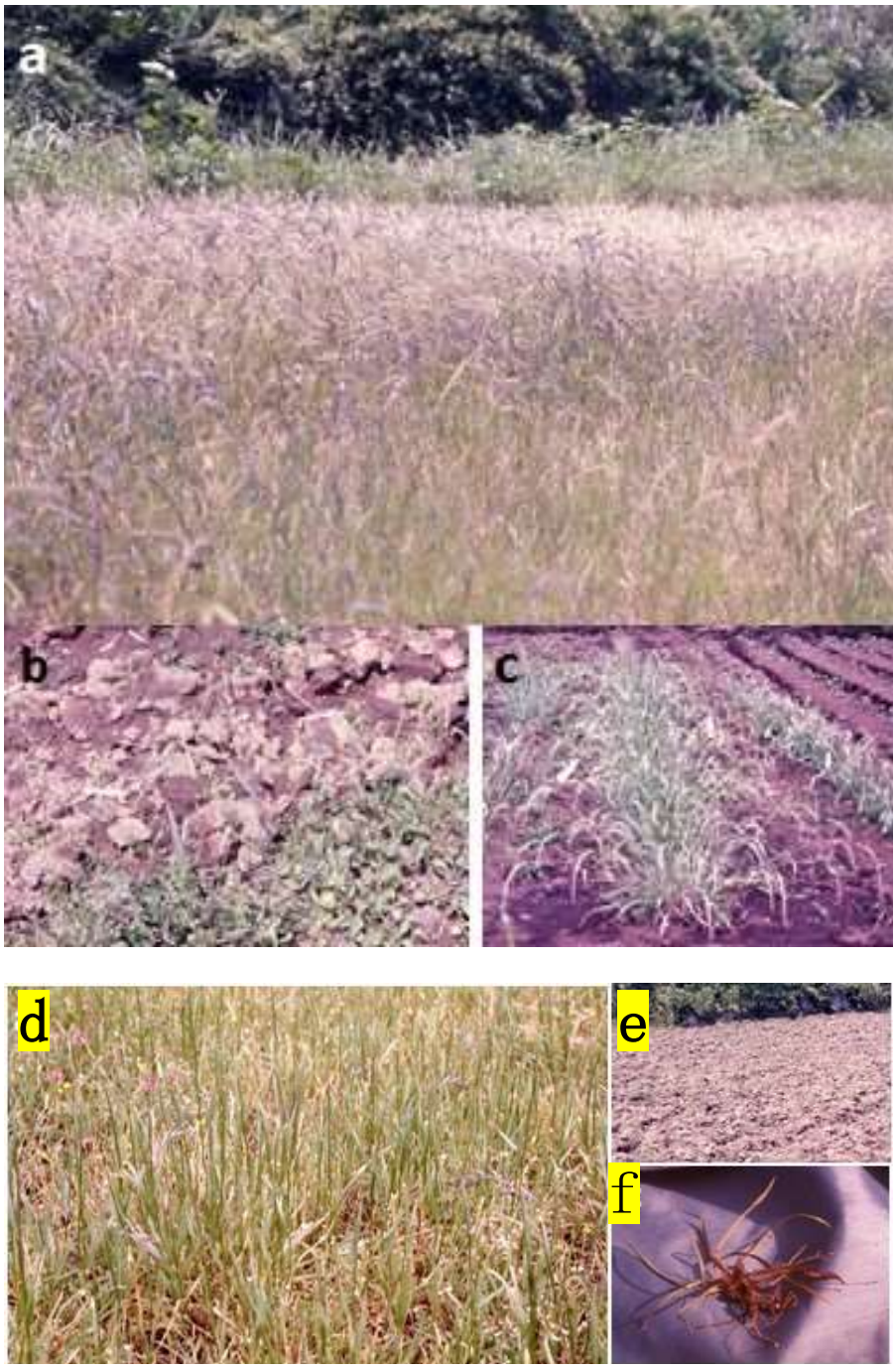


Figure 16. Weeds of genus *Agropyron*

a, early ecotype of *A. tsukushiense* in a fallow paddy field in Mishima,
Shizuoka prefecture; b, early ecotype on levee after spring plowing;
c, common type of *A. tsukushiense* at the field in Tokyo Gakugei University;
d, a sympatric population of early ecotype and *A. humidorum*;
e, after spring plowing in the same sympatric population;
f, sprouting from culm section in soil of fallow field after spring plowing.

It will be quite interesting that two closely related species adapted to the same environmental conditions display quite contrasted adaptive strategies to maintain their natural populations in winter fallow paddy fields.

Life history of genus *Secale*, tribe Triticeae

Rye has the strongest cold tolerance among the cereals grown in Temperate zoon. Farmers can sow both in winter and spring, but the yield is fewer in spring than in winter. An annual weedy group of *Secale* had differentiated from the perennial outcrossing group of *Secale montanum* in the Far East (Figure 17). This annual weed had lost the shattering habit, become erectness and larger grains under the domestication process, and then had domesticated to *Secale cereale* (outcrossing annual). On the other hand, the group of *Secale montanum* had differentiated into *S. silvestre* and *S. vavilovii* (self-pollinated annual). Under this process, the adaptation had occurred in the rearrangement of tree chromosomes and the change from perennial to annual.

Based on archaeological evidence, the domestication had been begun since ca. 3,000~4,000 BC. On the early 20 AD, a third of European people had eaten rye bread, while they had gradually changed to eat wheat bread (Stebbins 1950, 1957, 1958; Riley 1955, Khush and Stebbins 1961, Khush 1963, Suneson et al. 1969, Evans 1996).

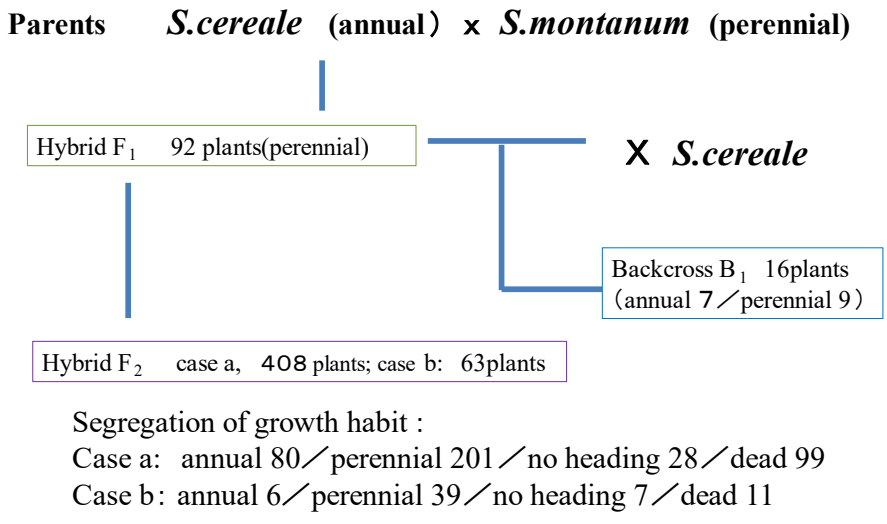
Figure 17. Hybrid F_1 (c; perennial) between *Secale cereale* (a; annual) and *S. montanum* (b; perennial)

The wild of *S. cereale* distributes from Central Europe, to Balkan peninsula, Anatolia, Israel, Trans-Caucasia, Iran, Central Asia; Afghanistan, and additionally disperses a small population isolated in South Africa. All species are diploid (2n=14). These species invade into the disturbed habitats by natural and artificial situation, especially wheat/barley fields such as weed. *Secale cereale* was the secondary crop which had been domesticated from the companion weedy rye. When wheat/barley had been dispersed to the north or highland region, these crops had been cultivated

under the cold and barren land. Occasionally, when the sever cold weather attacked to fields, the yield of wheat/barley decreased, but rye did not so much decrease. Therefore, *S. cereale* had become from a weed to a domesticated plant, because weedy rye had the strong tolerance against for cold (Vavilov 1926). The domestication process still continued to progress on fields (Sakamoto and Kawahara 1979).

This domestication process is very interesting when we compare with the process of Indian millets. Since the limiting factor is cold tolerance on the case of rye, while that is drought tolerance on the Indian millets. Namely, rye was domesticated from companion weed with wheat/barley, while Indian millets were domesticated from companion mimic weeds with rice. The main factor was drought tolerance for growing in the Decan Plateau (Kimata 2016).

As shown in Figure 18, the hybrid F1 between *S. cereale* (annual) and *S. montanum* (perennial) was perennial. The perennial growth habit was dominant, but the segregation rate of F2 is very complex, some plants were no heading and necrosis. The growth habits were not decided through a major gene. These materials were provided from Kyoto University.



Segregation of growth habit :
Case a: annual 80／perennial 201／no heading 28／dead 99
Case b: annual 6／perennial 39／no heading 7／dead 11

Figure 18. Artificial Hybridization of *Secale*

Annual is clearly dominant to perennial. There are so many characteristics related to the growth habit, that is, morphology, ecology and genetics. The number of nonproductive tillers was closely related to maintain dormant buds for polycarpic. However, *S. cereale,* annual has not maintain nonproductive tillers (late-emerging heads and foliage buds) by the end of July. The nonproductive tillers of *S. montanum* are 21~30, that of Hybrid F1 are 51~60 such as tussock. The annual of Hybrid F2, have not nonproductive tiller, but the perennial have so variable number of tillers, 1~90. Under the domestication process, the artificial selection performs for decreasing in the number of nonproductive tillers.

Domestication process of wheat

There are many important cereals and fodder crops belonging to sub-family, Festucoideae (family, Poaceae). In tribe Triticeae (Table 11), genus *Agropyron* consisted of only perennials,

Secale and *Hordeum* contained both annual and perennial, moreover *Triticum* and *Aegilops* consisted of only annuals (Satake 1964, Sakamoto 1991, 1996; Kihara ed. 1954; Clayton and Renvoize 1986).

Fifteen genera of tribe Triticeae, Gramineae, are classified into two major groups from their geographical distribution, the Mediterranean group and the Arctic-temperature group (Sakamoto 1973). The former consists of mostly self-fertilized annual species, while the latter largely perennial (both self- and cross-fertilized). The rapid adaptive differentiation of the Mediterranean group occurred during the formation of the Mediterranean climate most probably in the Quaternary. The climate is characterized by hot, dry summers and cool, moist winters. Those annual species have adapted to the conditions in winter. Therefore, most winter annuals seem to have originated in Mediterranean-Central Asiatic regions.

Compering the distribution and growth habit among 15 genera of Triticeaae, the most annual species had distributed from Mediterranean to Central Asia, while the most perennial species had distributed in circumarctic and temperate zones.

The region from Mediterranean to Central Asia have been dry land in summer under Mediterranean climate. Here had been the place where people had domesticated wheat, barley and so on, and they had created an ancient farming culture about 1,2000 BP. Those winter annuals germinate in autumn, overwinter, bloom, and then bear fruits (Sakamoto 1973). The Triticeae had differentiated quickly many genera and species through the adaptive radiation during the period when the topography had fluctuated rapidly by Alpin orogeny. Therefore, Triticeae indicates morphological diversity, close genetic relative. These species had hybridized among species and genera, then differentiated into allopolyploid or autopolyploid.

Table 11. Classification of 15 genera in the Triticeae（Sakamoto 1974）

Growth habit / Distribution	perennial	perennial+annual	annual	Rachis node with:
Mediterranean-Central Asistic regions	*Festucopsis* (2x)	*Haynaldia* (2x, 4x)	*Aegilops* (2x, 4x, 6x)	sollitary spikelets
		Secale (2x)	*Eremopyrum* (2x, 4x)	
			Henrardia (2x)	
			Heleranthelium (2x)	
			Triticum (2x, 4x, 6x)	
			Crithopsis (2x)	spikelets in group
			Taeniatherum (2x)	
Arctic-temperate regions of te world	*Agropyron* (2x, 4x, 6x, 8x, 10x)			solitary spikelets
	Asperella (4x)	*Hordeum* (2x, 4x)		spiklets in group
	Elymus (4x, 6x, 8x)			
	Psathyrostachys (2x)			
	Sitanion * (4x)			

* A North America genus　　Green character: genera used in this book

Modified Sakamoto (1973)

An annual is a plant that completes its life cycle and dies within 12 months, though the life span may overlap two calendar years because of wintering. There are two categories of annual life cycle, that which is ended more or less abruptly with flowering and seed set and that which has a potentially indefinite length of life that is usually ended within a year by a climatic event (Harper 1977). The former category is “true” annual in the strict sense, while the latter ecological annual and potential perennial. In the first category are many of the above grasses of Mediterranean climates

and arable land. On this arable land, their life for an annual in a crop is relatively safe until harvest and they can use the period in continuous cycle of growth. However, the adaptive value of the second category has been hardly studied yet.

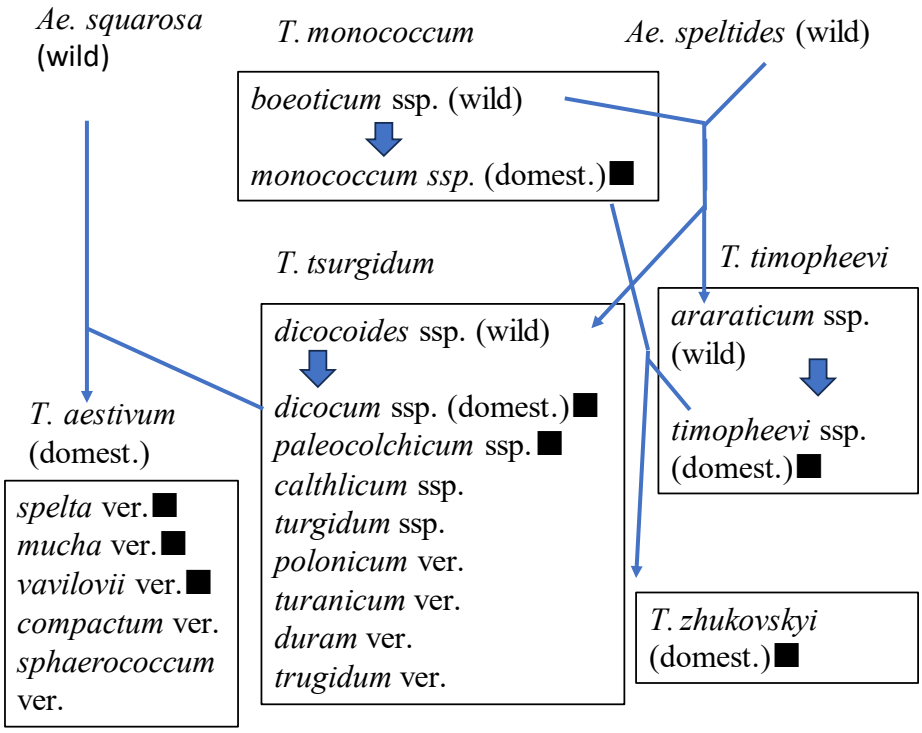


Figure 19. Origins and domestication of five groups in genus *Triticum*

→ Hybridization and doubling; ⬇ Domestication; ■ hulled grain.

(modified Sakamoto 1985,1996; Ohta original)

As shown in Figure 19, the domestication process had been progressed with such as annual. It had been very complicate, because many species were involved with the process. Sakamoto (1996) have categorized five groups of wheat as shown in Table 12. There are both wild subspecies and domesticated subspecies on *T. monococcum*, *T. turgidum* and *T. timopheevi*. Namely, those wheats had been domesticated from their wild subspecies, that is to say, from each *T. monococcum* ssp. *boeoticum*, *T. turgidum* ssp. *dicoccoides* and *T. timopheevi* ssp. *araraticum*. However, it was no wild species on *T. aestivum*.

Based on numerous papers, *T. aestivum* was domesticated as a hybrid between *T. turgidum* and *Ae. squarrosa*. *T. aestivum* was amphidiploid and a secondary crop which had involved with a companion weed. *Ae. squarrosa* had distributed from Trans-Caucasus, Eastern Turkey, Iran, Afghanistan, Central Asia to Western China. In Iran, *Ae. squarrosa* is a weed in wheat fields. T. aestivum had accepted D genome from the subspecies grown in East cost of Caspian Sea and Trans-Caucasus, and then it had been domesticated in this region.

Ehrendorfer (1965), Ornduff (1969) and Stebbins (1974) have pointed out the relationship between self-fertilized annual and heigher polyploidy, and then have avoided the disadvantage of homozygous genotype (Table 3 and Table 11). These species are cross-fertilized by wind pollination, and same species are self-fertilized with high self-pollination rate. However, tribe Triticeae indicates

that many polyploid spices do not relate to their growth habit.

We have gone on an expedition to Central Asia in 1993, and collected many species of Triticeae as shown in Table 12 and Figure 20. The number of accessions were *Triticum* (47), *Hordeum* (37), *Aegilops* (26), and *Agropyron* (17). Even now, their natural hybridization has continued among them on wheat fields. Those scientific names were identified in detail by Plant Germ-Plasm Institute, Kyoto University. We conducted their field experiment in 1994. For the comparison with those *Hordeum* species, *H. bulbosum* (2n=14, 28) was grown. *H. bulbosum* was a perennial with ryzom and polycarpy.

Table 12. Tribe Triticeae collected in Central Asia

Locality	Species	germination %	germination date
Kazakhstan	*Aegilops cylindrica* var. *typica*	100	May 22
Kazakhstan	*Ae. triuncialis* ssp. *eu-triuncialis* var. *typica*	100	May 24
Kazakhstan	*Ae. squarrosa* ssp. *eu-eusquarrosa* ver. t*ypica*	100	May 14
Kazakhstan	*Ae. crass* var. *typica* or var. *macrathera*	100	May 26
Kazakhstan	*Ae. crass* var. *macrathera*	100	May 22
Kazakhstan	*Ae. cylindrica* var. *pauciaristata*	60	May 27
Kazakhstan	natural hybrid; *Triticum aestivum* x *Ae*. sp. grew with *Ae. cylindrica* var. *typica* or *Ae. triuncialis*	0	
Kazakhstan	natural hybrid; *Triticum aestivum* x *Ae.* sp. grew with *Ae. cylindrica* var. *typica*	0	
Kazakhstan	*Ae. cylindrica* var. typica (sympatric)	100	May 18
Kazakhstan	*Hordeum spontaneum*	70	May 19
Kazakhstan	*H. vulgare* (6 rowed)	100	May 29
Kazakhstan	*H. vulgare* (2 rowed)	100	May 6
Uzubekistan	*H. vulgare* (6 rowed)	80	May 30
Uzubekistan	*H. vulgare* (2 rowed)	80	May 16
Uzubekistan	*H. spontaneum*	80	May 18
Kazakhstan	*T. aestivum*	90	May 14
Uzubekistan	*T. aestivum*	100	May 14
Uzubekistan	*Secale cereale*	100	May 24
Uzubekistan	*Triticale*	90	May 6

Figure 21 is shown an ancient field of wheat which is contaminated with many weedy species, for example, poppy, corn cockle, rye, oat and so on. Barley, *Hordeum vulgare* is a self-pollinating diploid with 2n=2x=14. Tetraploids have appeared spontaneously but are a negligible part of crop. The wild and weed races are usually designated *H. spontaneum* but, biologically, they belong to the same species as the domesticated races (Harlan 1995).

Figure 20. Natural hybridization of wheat in natural population, south Kazakhstan.

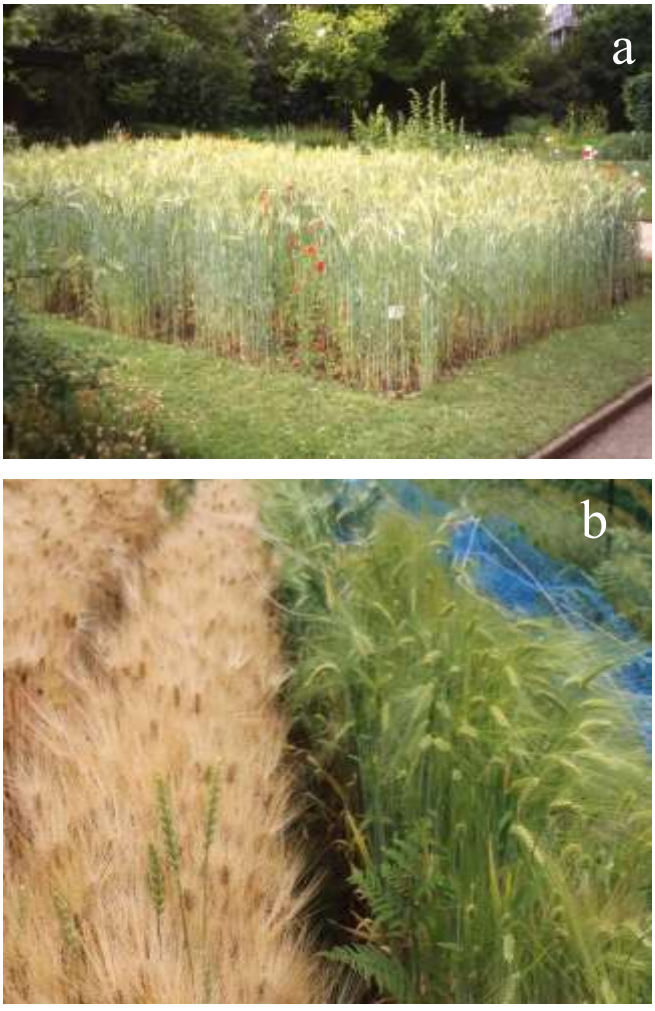


Figure 21. Wheat and Barley

a, an ancient wheat field (restoration) at the botanical garden of Free University Berlin, Germany; b, a barley field at Kosuge, Yamanashi, Japan.

Growth habit of *Sorghum*

Sorghum is highly diversified genus (de Wet 1978, Heran 1979, Sakamoto 1988). *Sorghum bicolor* (L) Moench is an annual plant (2n = 20, diploid, Figure 22) derived from *S. bicolor* var. *verticilliflorum* in Eastern Africa.

S. halepense (L) Pers. is a perennial weed (2n=40, tetraploid) and classified two subspecies. The Mediterranean ecotype is small plant with slender leaves, and distributes from Asian Minor to Western mountainous region in Pakistan. The tropical ecotype is a bigger plant with wide leaves (2n=20), and distributes from South India to the Islands of Southeast Asia.

S. propinquum (Kunth) Hitchcock is a perennial diploid (2n=20), and distributes from Sri Lanka to South India, Myanmar and the Islands of Southeast Asia. In Philippines, the hybrid between this spices and *S. bicolor* is a perennial and serious harm weed. The hybrids among *S. bicolor*, *S. halepense* and *S. propinquum* are perennial triploid/tetraploid which propagate vigorously by the ryzomes. Also, this sign means that a perennial growth habit is dominant trait. The purpose is breeding for the prevention of soil degradation and for fodder crop (Quinby *et al.* 1958, Cox *et al*. 2018).

In Central Asia, we collected 52 accessions, and classified into five types according to panicle form. The broom type (15 accessions) was a broom sorghum. This type was grown in kitchen gardens everywhere in West Turkestan and was an excellent material for making brooms because of the long sparse panicle (about 70 cm). The brooms were also sold in many bazaars. The weedy type (3) had a sparse panicle with many tillers. The sugar A type (7) had conical panicles and a large variation. The sugar B type (14) had a spear like panicle. The number of tillers was a few. These sugar types were maintained for genetic resources of sugar production at Leningrad University. The grain type (10) had a drooping ovate-compact panicle and few tillers. In this region, *S. bicolor* was remarkably various, but no perennial weeds.

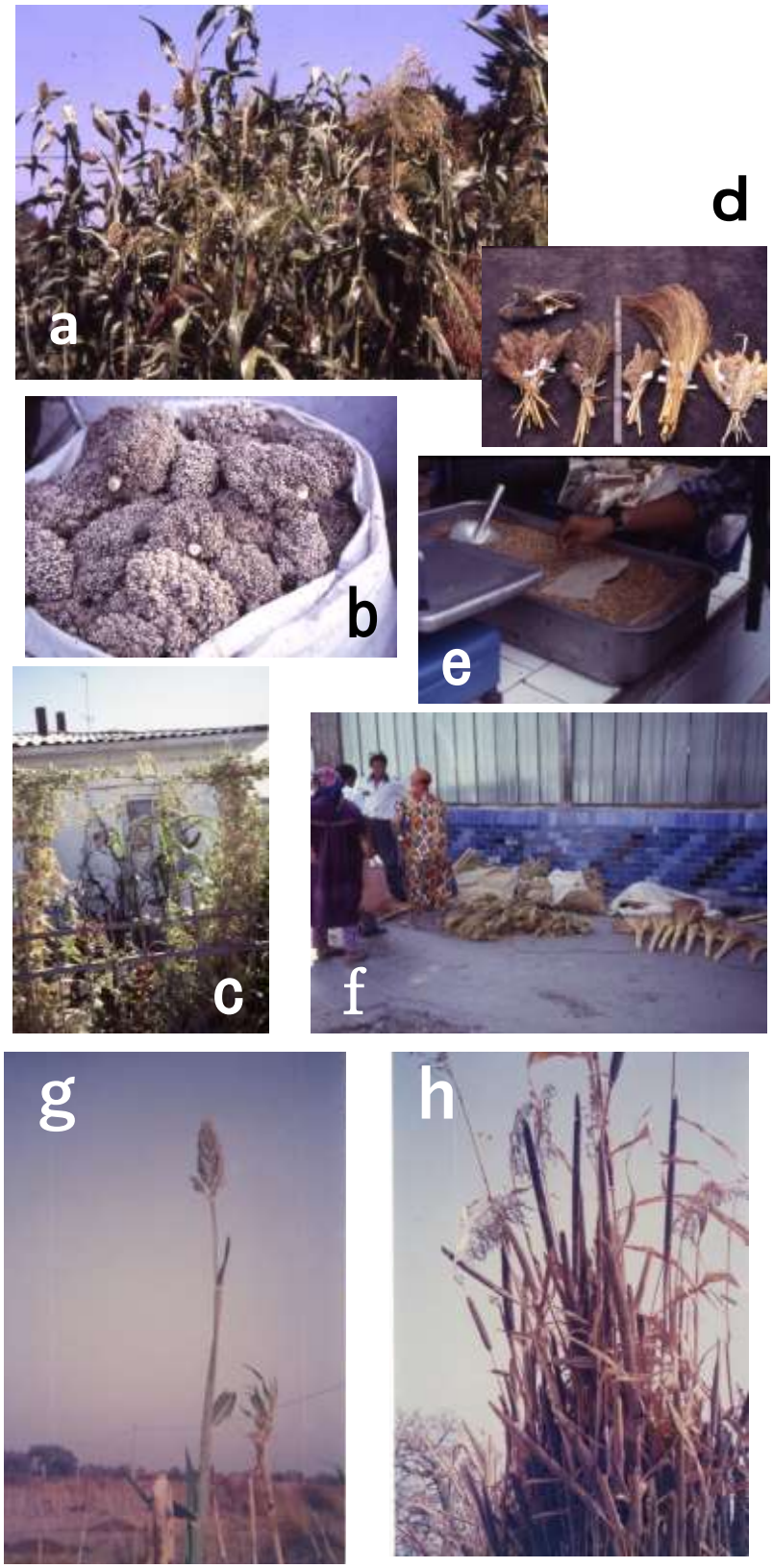


Figure 22. *Sorghum bicolor* in Central Asia and Africa

a, from India ; b, c, d, e, f; Bazar in Central Asia ; g and h, from Cote d'lvoire, Africa (Konishi photo).

Polyploidy and growth habit of genus *Oryza*

Genus Oryza, Poaceae consists of about 20 wild spices and two domesticated species as shown in Table 13. There are annual diploid (3 species), annual/perennial (5), perennial (7), and perennial tetraploid (8) (Oka and Coworkers 1980, Morishima 2001).

Domesticated rice, *O. sativa* is annual/perennial diploid. The ancestor, *O. rufipogon* is also annual/perennial growing in Tropical and Subtropical regions of Asia. Both species are complicated their speciation, because of their diversity. Ancestral species of *O. sativa* had been domesticated from a wild perennial *O. rufipogon*. *O. sativa* had been selected artificially and was become an ecological annual which increased seed production by self-fertility. At the same time, if it was warm winter, the plants grew by many ratoons after harvest and flowered again. It meant that *O. sativa* was perennial as for botanically. The natural selection has functioned on the habitats, at the same time, the artificial selection have been yearly worked by farmers under the cultivation cycle. Moreover, the upland rice had been secondary adapted to dry condition and then progressed to ecological annual growth habit under the drought or cold condition. The cultivation cycle was better within a year for farmers and plants.

O. glaberima Steud. is an annual diploid which had domesticated in West Africa. The ancestral species have been *O. barthii*, an annual diploid. Another African wild rice, *O. longistaminata* is a perennial diploid with self-incompatibility, but propagated both by seeds and subterranean stems.

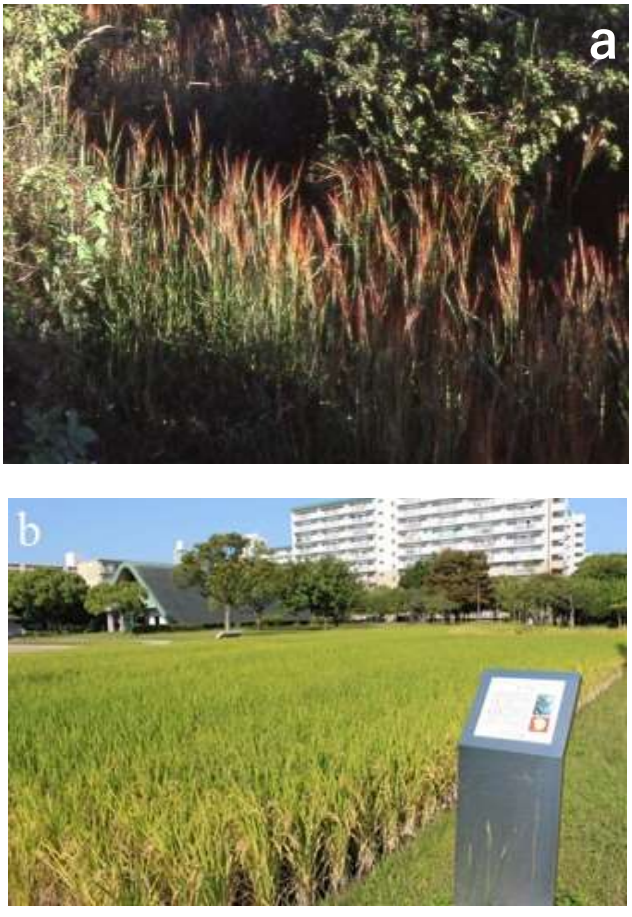


Figure 23. Rice paddy field

a, wild rice, *O. rufipogon* in Orissa, India; b, ancient rice paddy field (restoration) at archaeological site Itatsuke in

Kyushu, Japan.

Table 13. Some characteristics of genus *Oryza*

Genus *Oryza*	Chromosome number (2n)	Growth habit	Genome	Distribution
Section *Oryza*				
***O. sativa* ***	24	A/P	AA	around the world
***O. rufipogon* sensu lato**	24	A-P	AA	Asia, Oceania
***O. glaberrima* ***	24	A	AA	West Africa
O. barthii	24	A	AA	Africa
O. longistaminata	24	P	AA	Africa
O. meridionalis	24	A	AA	Australia
O. glumaepatula	24	A-P	AA	America
O. officinalis	24	P	CC	Asia
O. minuta	48	P	BBCC	Philippines
O. rhizomatis	24	P	CC	Sri Lanka
O. eihingeri	24	P	CC	Africa, Sri Lanka
O. punctata	24, 48	P	BB, BBCC	Africa
O. latifolia	48	P	CCDD	America
O. alta	48	P	CCDD	America
O. grandiglumis	48	P	CCDD	America
O. australiensis	24	A/P	EE	Australia
Section *Ridleyanae*				
O. brachyantha	24	A/P	FF	Africa
O. schlechteri	48	P	-	New Guinea
O. ridleyi	48	P	HHJJ	Asia
O. longiglumis	48	P	HHJJ	New Guinea
Section *Granulata*				
O. granulata	24	P	GG	Asia
O. meyeriana	24	P	GG	Asia

* domesticated species, A: annual, P: perennial, A/P: medium,
A-P: differenciation from perennial to annual.

R. x brachyceras is a sterile perennial, but maintains itself by means of vegetative reproduction. The reproductive systems of weedy *Rorippa* species may indicate each characteristic in the colonizing strategy into their habitats such as paddy field. There are asexual reproduction systems (apomixes in a broad sense) only in perennial species with a few exceptions. Perennial *Mazus miquelii* and *Cardamine lyrata* reproduce many ramets by stolons, *C. sucutata*, *Coix lacryma-jobi* var. *lacryma-jabi*, the common type of *Agropyron tsukushiense* var. *transiens*, and *A. humidorum* by stump itself and culms, while annuals *M. japonicus*, *C. flexosa* and *C. impatiens*, ecological annual *Coix lacryma-jobi* var *ma-yuen* and the early ecotype of *A. tsykushiense* var. *transiens* do not asexually at all.

An annual is a plant that completes its life cycle and dies within 12 months, though the life span may overlap two calendar years because of wintering. There are two categories of annual life cycle, that which is ended more or less abruptly with flowering and seed set and that which has a

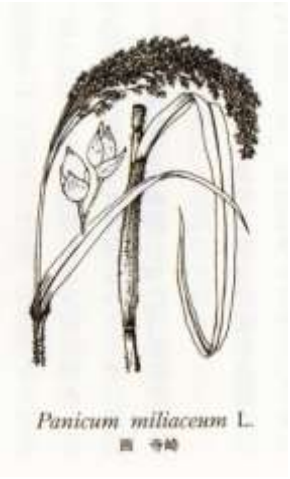
potentially indefinite length of life that is usually ended within a year by a climatic event (Harper 1977). The former category is “true” annual in the strict sense, while the latter ecological annual and potential perennial. In the first category are many of the above grasses of Mediterranean climates and arable land. On this arable land, their life for an annual in a crop is relatively safe until harvest and they can use the period in continuous cycle of growth. However, the adaptive value of the second category has been hardly studied yet.

A comparative survey of numerous examples of herbaceous colonizing species revealed the existence of three major colonizing types (Ehrendorfer 1965): perennial polyploid, annual self-pollinated and annual diploid species in Dipsacaceae, Asteraceae/Anthemideae, and Rubiaceae/Rubioideae. These types represent different evolutionary strategies and are characterized by different patterns in respect to ecological position, vegetative and reproductive characters, genetic system, and population structure. Also, Stebbins (1950) recognized several types of fertilization and growth habit of certain Gramineae and pointed out three general characteristics. (1) Annual species are relatively uncommon in cool temperature regions and predominant in warm, dry ones, with seasonal rainfall. (2) The annuals are almost exclusively self-pollinated, while the perennial species may be either cross- or self-fertilized, depending on the species. (3) Among the perennial species those with rhizomes are almost exclusively self-incompatible and cross-fertilized, while the caespitose, “bunch-grass” types shown various degree of self- or cross-fertilization.

Baker (1965) described the characteristics and modes of origin of weeds as colonizing species. The weeds show an annual, rather than a perennial growth habit, a wide environmental tolerance during growth, and striking developmental homeostasis in the sense that they produce flowers and seeds successfully in a wide range of conditions. They also show plasticity in size in response to environmental variation. Then, he (1974) proposed the ideal weed characteristics as follows. (1) Germination requirements fulfilled in many environments. (2) Discontinuous germination (internally controlled) and great longevity of seed. (3) Rapid growth through vegetative phase to flowering. (4) Continuous seed production for as long as growing condition permits. (5) Self-compatible but not completely autogamous or apomictic. (6) When cross-pollinated, unspecialized visitors or wind utilized. (7) Very high seed output in favorable environment circumstances. (8) Produces some seed in wide range of environmental conditions, tolerant and plastic. (9) Has adaptations for short and long-distance dispersal. (10) If a perennial, has vigorous vegetative reproduction or regeneration from fragments. (11) If a perennial, has brittleness, so not easily drawn from ground. (12) Has ability to compete interspecifically by special means (rosette, choking growth, allelochemics).

Actually, in colonizing species, it is in phases of germination and seedling establishment that their success or failure is most critically determined. Besides, the survival value of germination polymorphism is stressed. The germination polymorphism occurs in the adaptation to various environmental conditions, i.e., light, temperature (Harper 1965; Cavers and Harper 1966; Shimizu and Tajima 1975).

Chapter 4　Domestication process and dispersal of common millet, *Panicum miliaceum* L. (Poaceae) in Eurasia



My most important material was common millet（proso millet, *Panicum miliaceum* L.) for ethnobotanical studies. Upon reflection, I realized I should have the deep relationship to common millet in my childhood. The reason why was because the elder brother of my grand farther had send mochi made from waxy rice (white mochi) and common millet (yellow mochi) to our family lived in Nagoya. His paddy fields located at Yagami, in Nobi Plain with Kiso three rivers where was very famous rice production area. However, they had grown a few common millet on the upland around paddy fields. I liked a yellow mochi because the roasted cake with soy sauce was very tasty.

Domesticated species of genus *Panicum*

The genus *Panicum* (Poaceae) consists of about 500 species. These species have been used for wild grains, fodder, and medicine up to the present day, while three cereals, *P. miliaceum* L. (common millet), *P. sumatrense* Roth. (*samai*, little millet), and *P. sonorum* Beal. (*saui*, panic grass), were domesticated in different places and times. These are C_4 plants endowed with strong drought resistance, early maturation, and high nutrient content. *P. sumatrense* was domesticated from an ancestral species, *P. sumatrense* subsp. *psilopodium*, after around 2200 BC on the Indian subcontinent (Weber 1992), while *P. sonorum* was domesticated from *P. hirticaule* around 600 BC in northwestern Mexico (Nabhan and de Wet 1984). On the other hand, common millet was the most important grain crop that supported civilization around Eurasia over several thousand years starting in the Neolithic era. It is still cultivated and has various uses around the world. Although it is one of the oldest domesticated plants in Eurasia, the ancestral plant and place of origin have yet to be definitively determined. The place of origin of common millet has been discussed for many years (e.g., Bellwood 2005, Church 1886, de Candolle 1886, Gerard 1597, Harlan 1995, Jones 2004, Kimata 2009, Sakamoto 1987, Vavilov 1926). Vavilov (1926) proposed that the original place was North China, and Chun et al. (2004) suggested that common millet was domesticated in the southern part of the middle reaches of the Yellow River 8000–7000 years BP.

Harlan (1975) suggested that the two homelands were North China and eastern Europe. Nesbitt (2005) also suggested that it might have been domesticated independently in each area. Although both the wild ancestor and the place of domestication of common millet are unknown, it first

appeared as a crop in both Transcaucasia and China about 6000 BC. Zohary and Hopf (2000) suggested that common millet may have originated somewhere between the Caspian Sea and Xinjiang. The earliest sites bearing remains of common millet are in China and Europe from the seventh millennium BC, on opposite sides of the Eurasian continent (Jonse 2004). Furthermore, Sakamoto (1987) indicated that the area was located within Central Asia and the northwestern parts of the Indian subcontinent. Common millet was found from the sixth millennium BC at Tepe Gaz Tavilla in southeastern Iran (Meadow 1986). One explanation for its domestication could be an altered climate earlier in the Holocene. Meadow (1986) suggested that it might have been grown using floodwater runoff to supplement rainfall in this dry area as a spring or autumn crop. Similarly, farmers grow common millet in the Ganga area after winter floods. Detailed local analyses of this kind should underpin future considerations of common millet's origin in Central Asia to determine its possible routes of spread through this critical but underexplored area (Hunt and Jones 2006). However, the ancestor and original place of common millet have yet to be clearly determined.

Bellwood (2005) summarized recent thinking on the origin and spread of common millet based on recent archaeological contributions as follows. Common millet perhaps originated in Central Asia (Sakamoto 1987, Zohary and Hopf 2000). Neolithic settlers may have migrated from there to Afghanistan, the Russian steppes, or even western China. Common millet has been reported widely in the Neolithic cultures of Europe and the Eurasian steppes, but it would appear that the oldest known dates of cultivation are from North China from about 6500 BC onward. The first known occurrence in southeastern Iran was in the sixth millennium BC (Meadow 1986), c. 1550 BC in northwestern Iran (Nesbitt and Summers 1988), and about 2600 BC in South Asia (Fuller et al. 2001).

Morphological characteristics

The heading of common millet often occurred irregularly. Because the panicle flowered inside the leaf sheath 4–5 days before heading, the duration (days) to flowering from sowing was observed instead of the heading date. Generally, the duration of local varieties from high latitude areas was brief, but the number of days was remarkably variable. The varieties from China, Mongolia, the former USSR, Europe, and Japan (Hokkaido) flowered very early, by 40 days after sowing, while those from India and southern Japan flowered late, a third of them by 80 days. The varieties from China, Mongolia, the former USSR, Europe, and Japan (Hokkaido) had fewer leaves (5–10) on the main culm than those of southern and western Asia, Korea, and southern Japan (11 to 16). All of the varieties from Japan, Korea, and Nepal had only a few productive tillers (1 to 3), while the varieties from southern and western Asia, the former USSR (including Central Asia), and Europe indicated very broad variation (1–6), up to an extreme of 9 in 6.9% of samples from India.

Common millet is a densely piliferous plant. The hairiness of the uppermost internode was divided into four types: glabrous, sparse, moderate, and dense. Most varieties were glabrous or sparse, while the others were dense in Hokkaido (40.0%), western Asia (26.1%), and Europe (20.0%). The panicle was divided into five types: sparse, dense, compact, and intermediate values (Kimata unpublished). Most of the local varieties from Japan (Hokkaido), China, India, western Asia, the former USSR, and Europe were the sparse type, while the remaining varieties from Japan, Korea, and Nepal were the dense type. Only a few varieties from western Asia, the former USSR, and Europe were the compact type.

The lemma color on mature plants was classified into six colors: dark brown, brown, pale brown, ivory, orange, and grayish-green. The varieties from the former USSR and Europe showed large variations in color. Most grains from Japan (Hokkaido) and China were dark brown, but others from southern Japan were brown, pale brown, or ivory. In India, the grain color included grayish-green (45.6%) in addition to pale brown and ivory. The stigma color of the pistil in the mature stage was one of three colors: white, faint purple, or purplish-red. About 70% of the varieties showed the former two colors. Especially, in southern Japan and Nepal all the varieties had white stigmas except one. However, in Japan (Hokkaido), India, and western Asia over 73% of varieties had purplish-red stigmas. In Europe 28% of the varieties had purplish-red stigmas (Kimata unpublished).

The partial correlation coefficients of 14 characteristics are shown in Table 4. The coefficients greater than 0.6 under a 1% significance level were PH (plant height) and LN (number of leaves on the main culm) to days for flowering (DF). The DF, LN, FL and FW (length and width of flag leaf), and diameter of uppermost internode (DI) to PH; DF, PH, FW and DI to LN; PH, LN, and FL and FW to each other; DI to FL & FW; and PH, LN, FL, and FW to DI. The others, namely, number of tillers (TN), panicle length (PL), panicle type (PT), lemma color (LC), stigma color (SC), hairiness of uppermost internode (PI), and SH (shuttering) were not highly statistically significant. Therefore, the domestic varieties with late maturity are tall with many leaves, a large flag leaf that maintains effective photosynthesis during the growing season, and a bold culm that holds a heavy panicle.

Table 14. Partial correlation coefficients of 14 characteristics

	Days for flowering	No. of tillers	Plant height	No. of leaves on main culm	Length of flag leaf	Width of flag leaf	FL/FW	Panicle length	Diameter of uppermost internode	Panicle type	Lemma color	Stigma color	Hairiness of uppermost internode	Shattering
DF	1.000	0.005	0.835**	0.916**	0.501**	0.503**	-0.032	-0.400**	0.569**	0.363**	-0.055	0.131	0.078	0.027
TN	0.005	1.000	-0.203	-0.173	-0.216	-0.347**	0.297*	-0.259	-0.375**	-0.157	-0.118	-0.045	-0.008	-0.048
PH	0.835**	-0.203	1.000	0.907**	0.746**	0.736**	-0.095	-0.024	0.804**	0.543**	-0.030	0.015	0.036	0.057
LN	0.916**	-0.173	0.907**	1.000	0.594**	0.640**	-0.145	-0.310*	0.713**	0.372**	-0.009	0.172	0.056	0.066
FL	0.501**	-0.216	0.746**	0.594**	1.000	0.787**	0.164	0.179	0.726**	0.382**	0.039	-0.012	0.049	0.221
FW	0.503**	-0.347**	0.736**	0.640**	0.787**	1.000	-0.451**	0.170	0.814**	0.515**	-0.127	-0.123	-0.104	0.186
FL/FW	-0.032	0.297*	-0.095	-0.145	0.164	-0.451**	1.000	-0.052	-0.254	-0.226	0.217	0.123	0.202	0.002
PL	-0.400**	-0.259	-0.024	-0.310	0.179	0.170	-0.052	1.000	0.169	0.235	0.061	-0.240	0.052	-0.116
DI	0.569**	-0.375**	0.804**	0.713**	0.726**	0.814**	-0.254	0.169	1.000	0.548**	-0.033	-0.079	0.082	0.081
PT	0.363**	-0.157	0.543**	0.372**	0.382**	0.515**	-0.226	0.235	0.548**	1.000	-0.043	-0.335	-0.128	-0.142
LC	-0.055	-0.118	-0.030	-0.009	0.039	-0.127	0.217	0.061	-0.033	-0.043	1.000	0.358	0.102	0.043
SC	0.131	-0.045	0.015	0.172	-0.012	-0.123	0.123	-0.240	-0.079	-0.335*	0.358**	1.000	0.124	-0.011
HI	0.078	-0.008	0.036	0.056	0.049	-0.104	0.202	0.052	0.082	-0.128	0.102	0.124	1.000	0.053
SH	0.027	-0.048	0.057	0.066	0.221	0.186	0.002	-0.116	0.081	-0.142	0.043	-0.011	0.053	1.000

Controlled value is Iodine color reaction; * 5%, ** under 1% level significance.

The hierarchical cluster analysis of eight morphological characteristics and earliness is illustrated by using the group average method of SPSS. The 75 local varieties were divided into two major clusters, I, with five sub-clusters, and II, with two sub-clusters. Sub-cluster Ia consisted of 11 varieties, from Central Asia (3 varieties, former USSR), Uzbekistan (1), China (3), Spain (1), Germany (2), and Canada (1); Ib came mostly from Western Europe, including a few from Japan (Hokkaido), Mongolia, Uzbekistan, and Pakistan; Ic came mostly from Eastern Europe, including a few from Uzbekistan and the Indian subcontinent; Id consisted of three varieties from Afghanistan, Greece, and Pakistan; and Ie consisted of only one variety from India. Sub-cluster IIa consisted of

20 varieties, mostly from East Asia but including a few from Nepal (3) and Bulgaria (1). IIb consisted of 11 varieties, mostly from the Indian subcontinent and also a few from China (2), Japan (2), and Romania (1). The distribution of morphological characteristics generally showed two geographical trends, from Central and South Asia toward Europe via Asia Minor, and from China toward India via Nepal (to the south) and Japan via Korea (to the far east).

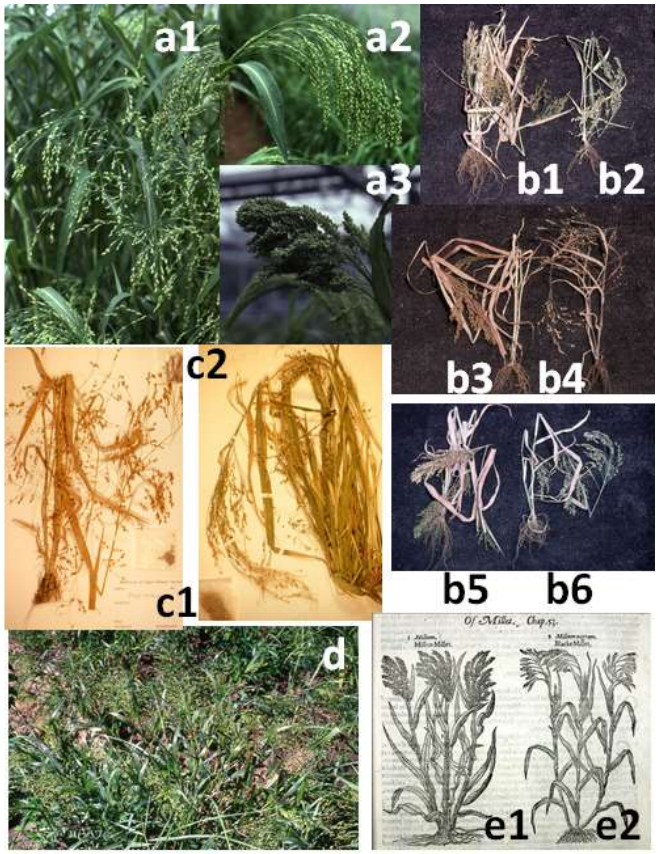


Figure 24. Morphology of common millet, *P. miliaceum*.

Types of panicle: a1, sparse; a2, compact; a3, dense. Domestic type and mimic weed in Central Asia: b1, b3 and b5, subsp. *miliaceum*; b2, an escaped weed; b4 and d, subsp. *ruderale*; and b6, subsp. *agricolum*. c1, a crop-like weedy biotype in Pakistan and c2, a F_1 hybrid between subsp. *miliaceum* and subsp. *ruderale*. e1/e2, *P. miliaceum* cultivated in Europe, about 17 century (Gerarde 1597). e1 and e2, European common millet in 17th century (Gerarde 1597).

Figure 24 shows typical panicle types such as sparse (a1), compact (a2), and dense (a3). It also shows a domestic type (b1) and an escaped weed (b2) in Pakistan; a domestic type (b3) and a weed, ssp. *ruderale* (b4), in Romania; a domestic type (b5) and a weed, subsp. *agricolum* (b6), in Uzbekistan; a crop-like weedy biotype, subsp. *miliaceum* (c1); and an F1 hybrid between a domestic type and the subsp. *ruderale* in Pakistan (c2), with both sparse and shattering panicles. It also shows a weed, subsp. *ruderale*, in Inner Mongolia (d, taken in 2004) and European common millet (e1 and e2) illustrated in a book (Gerarde 1597). The panicles of common millet can be divided into five types: sparse, compact, dense, and two intermediate types (relatively sparse or dense). Common millet is generally a densely piliferous plant, but the hairiness of the uppermost internode is very

variable. This trait can be divided into four types: glabrous, sparsely, moderately and densely piliferous.

Lyssov (1968, 1975) classified *P. miliaceum* L. into five groups based on the panicle types as follows. The panicle of race *miliaceum* was similar to that of a wild species. *Race patentissimum* had long, slender, and sparse panicles (a1), but it was very difficult to divide these two races, which were distributed from Eastern Europe to Japan. *Race contractum* had a droopy, compact panicle (a2). *Race compactum* had a cylindrical, erect panicle. *Race ovatum* had an oval, dense panicle (a3). Because these morphological characteristics did not clearly show a geographical cline, this classification was not indicative of their taxonomical characteristics. The taxonomy of common millet needs to identify intra-specific differentiation through a matrix of various characteristics. Scholz and Mikolāš (1991) classified *P. miliaceum* into three subspecies: *miliaceum*, *ruderale*, and *agricolum*. Subsp. *miliaceum* consisted of the cultivar form (b1, b3, b5) and crop-like weedy biotype (c1) in Pakistan, and also in Austria, Slovakia, and Canada, respectively. Subsp. *ruderale* (b4, d) was an escaped weed from subsp. *miliaceum* (b2) around the world, with the small grains shattering easily on its sparse panicle. Subsp. *agricolum* (b6) was a mutant race with characteristics intermediate between the domestic form and subsp. *ruderale*. This subspecies grew in maize fields because of its strong tolerance to herbicide. The two types of European common millet in the sixteenth century might have been the races *ovatum* (e1) and *patentissimum* (e2). A F_1 hybrid (c2) between subsp. *miliaceum* and subsp. *ruderale* was grown.

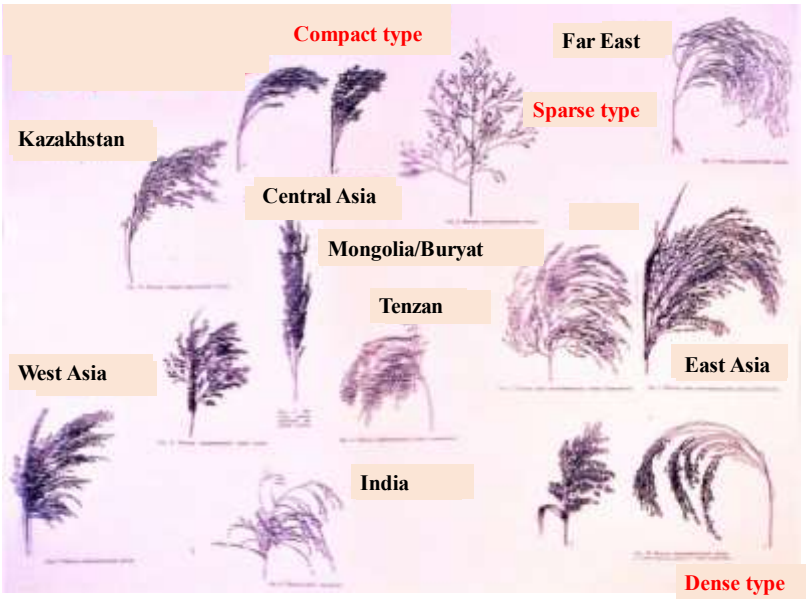


Figure 25. Variation of spike of *P. miliaceum* in Asia
Lyssov (1968, 1975) modified

Variation of common millet in Hokkaido, North Japan

We had started our field study in Kanto Mountains, Central Japan since 1974 (Kimata et al. 1978, Kimata et al. 1979, Kimata and Yokyama1982). Moreover, we have been to Hokkaido, Noth Japan since 1981 (Kimata *et al*. 1986, 1995, 1996, 1997), because Ainu people have inhabited here. They have cultivated *P. miliaceum*, *Echinochloa utilis* and *Setaria italica* traditionally even now. We

had visited many farmers in South Hokkaido as shown in Figure 24. We detected that the relict local varieties of millet had been cultivated mainly by Ainu people at Biradori along Saru river. We had been given the seeds for our study from the farmers. The breakdown of common millet was 14 accessions from farmers along Saru river, the other one at Oshima peninsula, and one more at Sharicho.

The 14 local varieties from Biradori were used for cultivation test on their morphological characteristics as shown in Table 14. These were categorized 8 types through the combination of 7 characteristics, that is, maturity, No. of tillers, spiklets/spike Length rate, 1000 grains (g), glume color, empty glume color, and heiriness on neck of spike (Kimata *et al*. 1986). A type (6 accessions) and B type (2) indicated the features of a typical indigenous variety. These two types indicated the following characteristics, early maturity, a few tillers, low rate of spikelets/spike length, heavier 10000 seeds, dark brown glume, red purple empty glume, and more hairiness on neck of spike, when those were grown in Tokyo. The others were assumed the following two cases. One was the strain had adapted to the environment in Hidaka area after it was introduced from Honshu since Meiji period. Another was the strain had crossed naturally/artificially with the introduced strain. Those had diverse variation under the natural/artificial selection. These main characteristics were late maturing, orange glume, and glabrous on neck of spike. Moreover, Noboru Tachibana had grown three local varieties from Kanto, Hokuriku and Hokkaido on the comparative field experiment (1n 1984). With the result that the plant height was only deferent long comparing to the Cultivation result in Tokyo, but the others of stable characteristics were same as red purple empty glum, and more hairiness on neck of spike.

The variation of spike types were compact types (8 strains), sparse types (4) and dense type (2). By the iodo-starch reaction, the albumen starch of all strains (total 14) indicated grape color which meant the medium between waxy and non-waxy and was speculated about polyploidy.

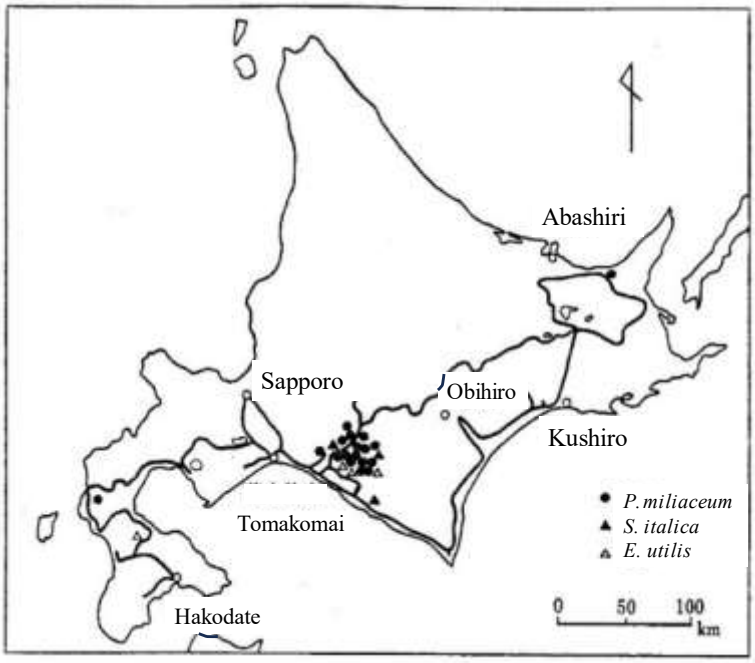


Figure 26. Field survey route and distribution sites of millet (1981~1984)

Table 15. Characteristics of *P. miliaceum* from Biratori and the others in Hokkaido

Type	A	B	C	D	E	F	G	H
Characteristics								
Maturity	early	early	early	early	medium	medium	Late	Late
Tillers	a few	a few	many	a few	a few	a few	many	a few
Spiklets/Spike Length rate	a few	a few	a few	a few	many	a few	many	many
1000 grains (g)	medium	heavy	medium	light	light	medium	light	light
Glume color	dark brown	dark brown	dark brown	dark brown	dark brown	orange	dark brown	orange
Empty glume color	red purple	red purple	red purple	green	green	green	green	red purple
Heiriness on neck of spike	hairy	many	many	hairy	many	hairy	hairless	hairy
No. of strains	6	2	1	1	1	1	1	1

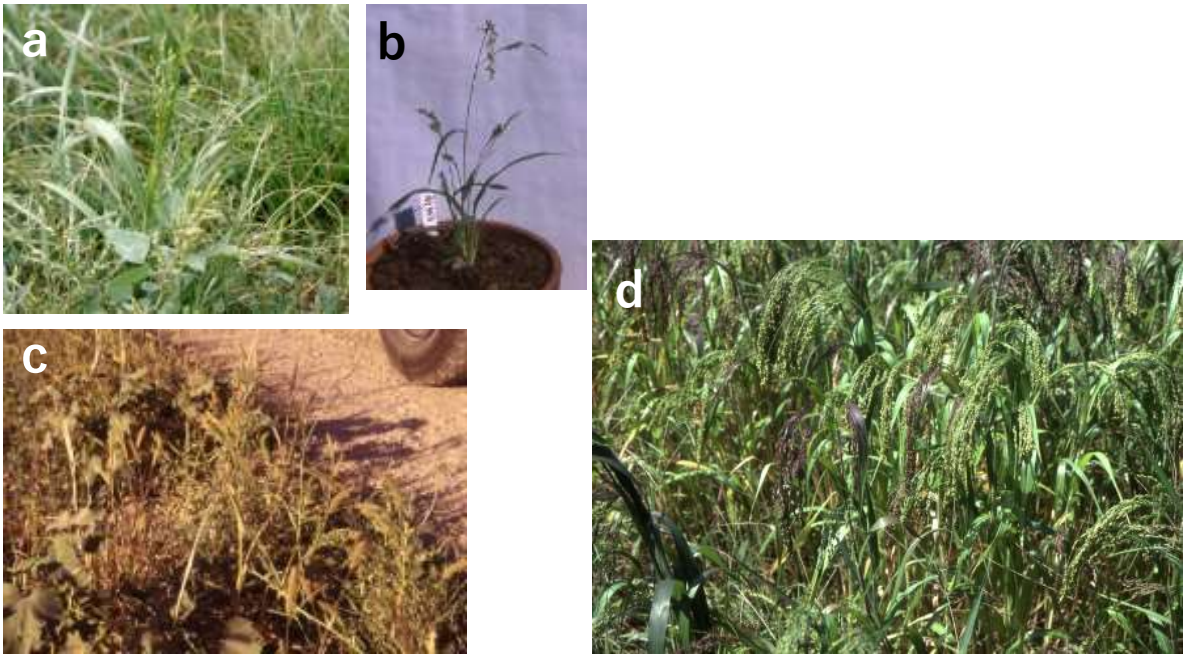


Figure 27. Wild type and domesticated type of *Panicum miliaceum*

a, a wild type, *P. miliaceum* ssp. *ruderale* in Inner Mongolia; b, a local variety C type of Osachinai, Hokkaido cultivated at Koganei, Tokyo; c, an escaped type on the roadside near Tashkent, Uzbekistan; d, local variety (purple spike) and introduced variety (green spike) on a mix-sowing field at Hobetsu, Hokkaido,

Table 16. Geographical variation of *P. miliaceum* in Eurasia

Locality	Japan		East/South Asia	West/Central Asis	Europe
Characteristics	**Hokkaido**	**South of Honshu**			
Headinng days	early	medium/late	medium/late	medium/late	medium
No. of leaves	a few	medium/many	medium	a few/medium	a few
Plant height	short	medium/long	medium/long	medium/long	short
No. of tilers	a few	medium	medium	a few/many	a few
No. of spikelets	a few	medium/many	medium	a few/medium	a few
1000 grains (g)	light/heavy	light/lighter	heavier	heavier	light/heavier
Glume color	dark brown	dark brown/orange/white	dark brown/orange/white	orange/white	white
Empty glume color	red purple(green)	green	green	red purple/green	red purple
Heiriness on neck of spike	hairy	glabrous	glabrous	hairy	many

Crossability among Eurasian varieties and morphological characteristics of F_1 hybrids

The crossability among six testers was estimated by their fructification rates. The florets (range 5 to 50, average 17.0) on panicles (1 to 3, average 1.2) were artificially crossed with the tester pollen of each variety, yielding an average fructification rate of 4.8%. Crossing tests were conducted between 351 combinations yielding 117 F_1 hybrids fructified. The artificial cross pollination of common millet was technically very difficult because the quite irregular flowering happened often before heading, and anther dehiscence was very sensitive to daily weather conditions and it did not open entirely under wet conditions on rainy days. Because of this, the observed crossability was relatively low, ranging from 0 to 63.9%. The F_1 hybrid was obtained from 18 varieties. The crossability of ovum parents was lower than that of pollen parents among the testers. One to 15 seed grains were obtained from each variety, and the germination ratio was observed in only 105 strains of the F_1 hybrid. Most seeds germinated well, while the others did not germinate or necrotized immediately after germination. All of the F_1 hybrid plants had good pollen fertility of over 78%.

Crossability among varieties was summarized to each country and region as shown in Table 5. The French tester had the largest number of sound F_1 plants (41.2%) with European varieties. The Central Asian tester made F_1 plants (58.8%) only with East Asian varieties. The Indian tester made F_1 plants with East Asian (33.3%) and South Asian (30.8%) varieties. The Chinese tester (p51) made F_1 plants with East Asian (45.0%) and European (45.0%) varieties. The Japanese tester (p60) made F_1 plants with East Asian (45.0%), Central Asian (37.6%), and South Asian (38.9%) varieties. The weed tester (p32, subsp. *ruderale* from Romania) made F_1 plants with South Asian (35.7%) and Central Asian (28.6%) varieties. The pollens of subsp. *ruderale* could artificially fertilize the ovum of domestic varieties, but the counter practices could not at all. Notably, a domestic variety with sparse and shattering panicles (PC57-2 from Hokkaido, Japan) made F_1 hybrids with the testers from Central Asia, India, and Japan, but not with the others.

Table 17. Crossability (%) among local varieties

Ovum / Locality	No. of varieties	Pollen					
		France	p32 Weed	Central Asia	India	p51 China	p60 Japan
East Asia	21	23.5	16.7	58.8	33.3	45.0	45.0
Central Asia	8	16.7	28.6	20.0	0	0	37.6
South Asia	19	26.7	35.7	29.4	30.8	25.0	38.9
Europe	20	41.2	16.7	17.6	17.6	45.0	21.1
Canada	1	0	0	+	0	0	0
Weed type (Romania)	1	0	0	0	0	0	0
Total combinations	70	56	58	47	65	67	58

+, with another variety.

The French tester made the largest number of fertile F_1 hybrids with European varieties, the Central Asian tester with East Asian varieties, the Indian tester with East and South Asian varieties, and the Chinese tester with East Asian and European varieties (Fig. 5). Central Asian varieties were infertile when crossed with Indian or Chinese ovum parents similar to that when crossed with a weed (p32). These data suggested that common millet was dispersed from Central Asia to China and Europe, respectively, and then dispersed indirectly to South Asia and East Asia. The weed (p32) was not a crop-like weedy biotype because it was isolated reproductively and made no fertile hybrids as an ovum parent, notwithstanding the assured fructification among varieties from all regions in the reverse as a pollen parent. However, it might still be possible that subsp. *ruderale* was an ancestor, since it made fertile F_1 hybrids between the other varieties.

The panicle type of F_1 hybrids with the sparse-panicled Indian tester was also sparse. The F_1 hybrids with the dense-panicled Japanese tester (p60) had sparse panicles when combined with sparse varieties and dense panicles when combined with dense varieties. The F_1 hybrids between varieties with middle-type panicles generally also had middle-type panicles.

Common millet is generally a densely piliferous plant, but the hairiness of the uppermost internode was highly variable. This trait was divided into four types: glabrous, sparsely, moderately and densely piliferous. The F_1 hybrids between the moderate varieties (e.g., p9, p11, and p56) had a moderate internode except for p8 (glabrous). The F_1 hybrids with the glabrous testers from Central Asia, China, and Japan mostly had a glabrous internode except for a few in p2, p53, and p9 (moderately). The F_1 hybrids between the moderate or dense varieties and the dense Indian tester were varied widely between glabrous, sparsely and moderately, while an F_1 hybrid between a glabrous variety from Japan (Hokkaido) and the moderate Indian tester had a glabrous internode.

The variation in Central Asia

Several characteristics of common millet are shown in Table 18. Generally, the panicle form is classified into three types, A, compact; B, sparse; C, small sparse, but it displayed remarkable variation in detail. Lemma color was divided into four grades, that is, pale brawn, brown, dark brawn, and grey. The seed germination rate that was mostly good at over 60%, except for 5 accessions. The number of tillers varied from 1.0 to 3.6 on average. The flowering date was mostly short, ranging from 26.0 to 40.6 days. The number of leaves on the main culm was mostly small ranging from 5.8 to 12.2. Stigma color was dividable into three grades, pale purple, purple and reddish purple.

Most of A type with the compact panicle had brown lemma, a few tillers, a middle flowering date and a pale purple stigma. B type with sparse panicle had a pale brown or gray lemma, relatively more tillers, a middle flowering date and a purple stigma. B type resembled the landraces of Hokkaido (North Japan) in panicle form, number of tillers, flowering date, number of leaves and stigma color. These are very important characteristics for considering any northern dispersal route into Japan. C type with small sparse panicles was an associated mimic weed (*P. miliaceum* ssp. *ruderale* (Kitag.) Tzvelev) and had grayish lemma, relatively more tillers, early flowering date, fewer leaves on the main culm and a pale purple stigma. C type also showed a remarkable shattering and deep dormancy of seeds. These are typical traits of weedy plants. These data support the possibility the West Turkestan was the domestication center of common millet, and that the weed (*P. miliaceum* ssp. *ruderale*), as be an ancestor of common millet.

Materials and Methods for several experiments

A series of studies was started on common millet's morphological and ecological characteristics, followed by studies of the secondary compounds in the grain (Kimata and Negishi 2002, Kimata et al. 2007). The present paper is concerned with the ancestor, domestication, and geographical dispersal of common millet in Eurasia. The purpose is to examine these questions using all botanical characteristics, including biocultural diversity (traditional food styles and archeolinguistic data) and genetic characteristics (crossability, F_1 hybrids and AFLP markers).

Many endemic varieties and relatives of *Panicum miliaceum* L. have been collected from all of Japan and the Eurasian continent through field surveys since 1973. Grain samples (650 accessions) were collected along the survey route and the voucher herbarium specimens were deposited at Tokyo Gakugei University (Tokyo, Japan). Information on agricultural practices, grain processing, food preparation, and vernacular names was gathered from local farmers.

Some of these accessions, 441 local varieties, were selected and grown at the greenhouse of Tokyo Gakugei University, Japan to compare their morphological and ecological characteristics starting on July 10, 1986. These local varieties included 132 from Japan, 39 from eastern Asia, 78 from the former USSR, 90 from southern Asia, 26 from western Asia, 43 from Europe, two from Africa, and one from Canada (Kimata and Negishi 2002).

Ten grains of each strain were sown in a seeding box with a row spacing of 8 cm and seed spacing of 2 cm. Two weeks after sowing, germinated plants were transplanted into the greenhouse, with 30-cm row spacing and 15 cm between plants. Chemical fertilizer (N:P:K = 8:8:5) was supplied at 100 $g \cdot m^{-2}$. Five plants of each strain were measured for traits, including the duration to flowering (days), number of leaves on the main culm, number of productive tillers, hairiness of the uppermost internode, panicle type, lemma color, pistil stigma color, and others. These morphological and ecological data were analyzed statistically using partial correlation coefficients and hierarchical cluster analysis in SPSS (ver. 21, IBM Corp).

Moreover, 70 local varieties, including six pollen testers, were selected and grown in the greenhouse from 1990 to 1995. These accessions included 21 from eastern Asia, 8 from Central Asia, 19 from southern Asia, 21 from Europe, and one weed, *P. miliaceum* subsp. *ruderale*, from Romania. The crossability among the 70 Eurasian varieties and the morphological characteristics of their F_1 hybrids were examined in the six pollen testers from France, Central Asia, India, China, Japan, and

a weed.

Table 18. Several characteristics of common millet cultivated in Tokyo, Japan

Collection no.	Panicle form	Lemma color	Germination rate (%)	No. of tillers	Flowering date (days)	No. of leaves	Stigma color
A type							
93-6-26-1a-3	compact	brown	100	1.0	36.8	10.8	pale purple
93-6-29-2-15-1	compact	gray brown	60	1.0	35.8	10.4	pale purple
93-7-2-2-1	compact	brown	100	1.6	39.4	10.6	pale purple
93-7-6-1-25k	intermediate	brown	80	1.2	35.0	10.2	pale purple
93-7-7-1b-1-1	compact	brown	70	1.6	36.8	10.2	pale purple
93-7-13-2-3-1	compact	brown	20	1.5	37.0	10.5	pale purple
93-7-26-1	compact	brown	100	1.8	36.2	9.8	pale purple
93-7-26-1-1n	compact	brown	100	2.0	38.0	10.8	pale purple
93-7-27-1-7n-1	intermediate	brown	100	1.6	38.2	9.6	pale purple/purple
93-8-5-1b-1	compact	brown	60	1.6	37.8	10.4	pale purple
93-8-5-2-1-1	compact	pale brown	70	2.2	41.8	11.5	pale purple
93-8-7-1a-3	compact	brown	60	1.3	39.3	11.0	pale purple
93-8-7-1a-6	compact	pale brown	100	2.0	45.0	11.6	pale purple/reddish purple
93-8-14-1-2-1	compact	dark brown	80	2.6	30.6	7.4	pale purple
93-8-14-1-2-2	compact	brown	90	1.2	40.0	10.8	pale purple
93-8-14-1-3-1	compact	brown	40	1.8	36.5	10.3	pale purple
B type							
93-7-6-1b-3-1	sparse	pale brown	70	2.4	39.2	11.4	purple
93-7-13-2-1	sparse	pale brown	100	2.6	41.0	12.2	purple
93-7-15-1-4-1	sparse	pale brown	100	2.2	40.6	10.8	pale purple/purple
93-7-15-1-4-2	sparse	gray	100	3.5	40.8	11.5	purple
93-7-27-1-1n-1	sparse	pale brown	100	2.6	39.3	10.8	purple
93-7-27-1-1n-2	sparse	gray	100	3.0	42.4	10.2	purple
93-7-27-1-7n-2	sparse	gray	100	3.4	32.8	7.6	reddish purple/pale purple
93-8-2-1-1-1	intermediate	pale brown	100	2.0	46.0	12.0	pale purple
93-8-2-1-1-2	intermediate	brown	100	1.8	44.0	10.6	pale purple
93-8-2-1-1-3	sparse	gray	80	2.2	44.0	11.2	pale purple
93-8-2-1-2	intermediate	pale brown	70	2.2	45.8	12.8	pale purple
93-8-5-2-1-2	sparse	gray	60	3.6	42.4	11.2	purple
93-8-7-1a-5-1	sparse	pale brown	100	2.5	38.0	10.8	pale purple
93-8-7-1a-5-2	intermediate	gray	100	1.8	42.4	11.4	pale purple
93-8-7-1b-1-1	sparse	pale brown	100	2.8	45.0	10.6	pale purple/purple
93-8-7-1b-1-2	sparse	gray	100	2.2	45.6	11.4	purple/pale purple
93-8-7-1d	sparse	pale brown	100	2.6	43.2	11.4	pale purple/purple
93-8-14-1-3-2	sparse	dark brown	30	2.5	34.0	9.5	pale purple/purple
C type							
93-6-29-2-15-2	small sparse	gray	40	3.5	26.0	6.0	pale purple
93-7-7-1b-1-2	small sparse	gray	90	3.0	27.8	5.8	pale purple
93-7-13-2-3-2	small sparse	gray	40	2.0	32.0	9.0	pale purple
93-8-14-1-1	small	dark brown	100	2.8	29.4	6.0	pale purple

Ten grains of each of 75 accessions were sown by the same method as above on Oct. 4, 2007. DNA extraction was performed on young leaf tissue ground in liquid nitrogen and incubated in 1.5-ml tubes containing 0.5 ml of buffer A for 10 min at 60 °C by using CTAB (hexadecyl-trimethyl-

ammonium bromide) methods (Murray and Thompson 1980). The AFLP procedure was performed according to Applied Biosystems (2005), Bai et al. (1999), and Suyama (2001) with some modifications. Amplification reactions were performed according to the same protocol. Five primers associated with *Eco*RI (E+AAC, E+AAG, E+AGG, E+ACT, and E+ACA) were used in combination with 5 primers associated with *Mse*I (M+CAG, M+CTG, M+CTA, M+CAT, and M+CAA). Five microliters of amplification products were loaded onto a 5.75% denaturing polyacrylamide gel (LONZA) and electrophoresed in 1× TBE for 1 h. Bands were detected using the silver staining protocol described by Cho et al. (1996). The bands were detected on the gel at the finest level of sensitivity by Lane Analyzer (ATTO), the raw data were adjusted, and then the visible and reproducible bands were scored for accessions as present (1) or absent (0). The dendrogram of the AFLP markers was constructed using the neighbor-joining and UPGMA methods (Nei and Kumar 2000) with the bootstrap analysis (PAUP* ver. 4.0) and the hierarchical cluster analysis (group average method, SPSS ver. 21) on all data matrices of 75 local varieties.

Table 19. Materials used of *P. miliaceum* and the relative species

Area collected	Sample no.	Total
Japan	p1, p2, p30, p37, p38, p39, p60	7
Korea	p3, p4, p23,	3
China	p5, p14, p15, p19, p29, p51	6
Mongolia	p18, p20,	2
Nepal	p13, p16, p52	3
Bangladesh	p50	1
Uzbekistan	p68, p69, p70	3
Afghanistan	p6, p7,	2
India	p53, p54, p55, p56, p57, p61; (*P. sumatrense*) pm2, pw1, pw68	9
Pakistan	p58, p59,pp62, p63, p64, p65, p66, p67	8
Turkey	p17, p33, p91 (weed)	3
Greece	p36,	1
Romania	p9, p10, p24, p31, p32, p34, p35	7
Czechoslovakia	p21	1
Yugoslavia	p40	1
USRR-E	p41, p43, p46, p49	4
USSR-CA	p42, p45, p48	3
Poland	p44	1
Bulgaria	p22	1
Germany	p25, p26, p27, p28,	4
Belgium	p8	1
France	p11	1
Spain	p12	1
Canada	p47	1
USA	(*P. sonorum*) p111	1
Total		75

Phylogenetic tree by AFLP markers

The AFLP markers of 75 local varieties were analyzed by PAUP* ver. 4.0 and SPSS ver. 21, including neighboring joint and UPGMA methods with the bootstrap test. The interspecific differentiation of *Panicum miliaceum*, *P. sumatrense*, *P. sonorum*, and their relatives is illustrated in Fig. 4 (neighboring joint tree, PAUP*). Clear interspecific differentiation among there species of *Panicum* were noted, including the domestic and weed types of *P. miliaceum* from Pakistan and

Uzbekistan, and the other species, *P. sumatrense* and *P. sonorum* in the bootstrap test. However, the phylogenic differentiation of common millet was not as clear among varieties based on the bootstrap test (200 replicates), as shown in Fig. 5 (UPGMA tree, PAUP*), although there was a geographical trend in the dendrogram.

The 75 varieties were divided into two major clusters: I with six sub-clusters and II with three sub-clusters. Sub-cluster Ia consisted of five varieties from Germany, Romania (subsp. *ruderale*), China, and Japan (2 varieties). Ib consisted of seven varieties from Turkey, Greece, Romania (2), and Japan (3). Ic1 consisted of six varieties from Yugoslavia, the European portion of the former USSR (USSR-EU, 2), the Central Asian portion of the former USSR (USSR-CA, 2) and Poland. Ic2 consisted of ten varieties from Canada, USSR-EU (2), USSR-CA, China, Nepal, Bangladesh, and India (3). Ic3 consisted of eight varieties from India (3), Pakistan (4), and Japan. Id consisted of seven varieties, including Pakistan (4, with two weed types) and Uzbekistan (3, with one weed type). Sub-cluster IIa consisted of only two varieties from Afghanistan. IIb consisted of 9 varieties from China (2), Nepal (2), Romania (2), France, Spain, and Belgium. IIc consisted of 11 varieties from China, Korea, Mongolia (2), Turkey, Bulgaria, Romania, Czechoslovakia, and Germany (3). The distribution of AFLP markers generally showed two geographical trends, from Afghanistan and Mongolia toward Europe and Nepal via China (to the west and east), and from Uzbekistan and Pakistan toward India and Eastern Europe via USSR-CA/EU (to the south and west).

On one hand, based on the hierarchical cluster analysis (group average method, SPSS), only two clusters were detected among 51 varieties. Cluster I consisted of five varieties, including three weed types from Pakistan and Uzbekistan, while Cluster II consisted of 46 varieties from the other regions.

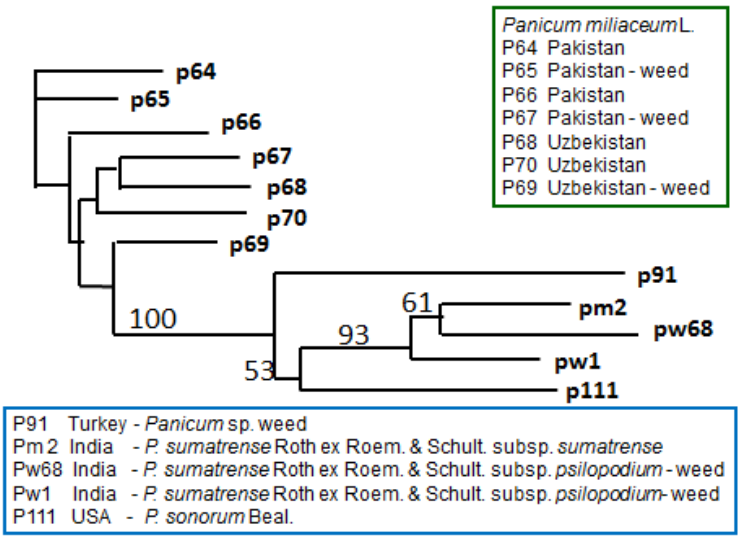


Figure 28. Interspecific dendrogram of three domestic species in genus *Panicum* by AFLP markers

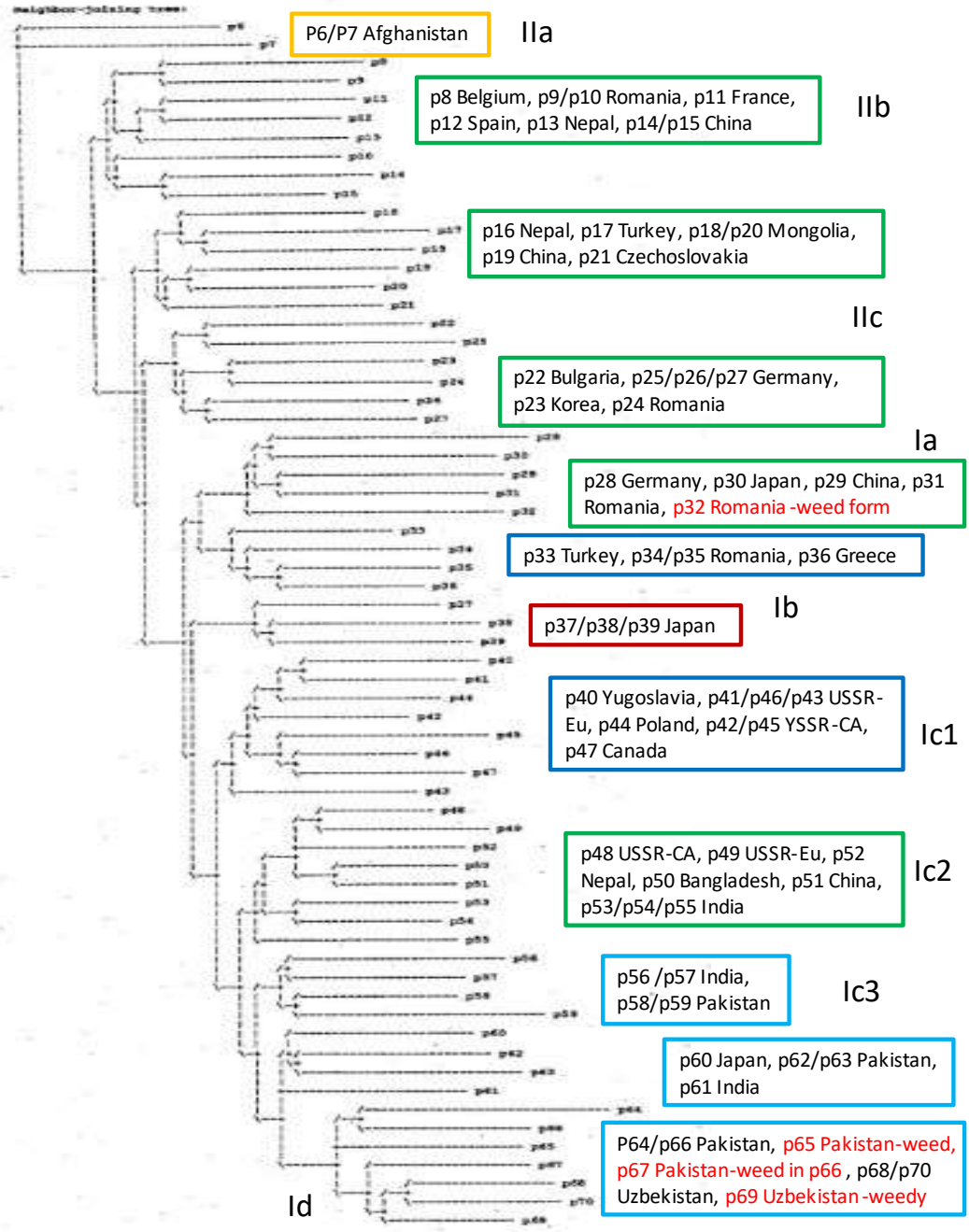


Figure 29. Intraspecific dendrogram of common millet by AFLP markers.

Food preparation and secondary compounds in grain

The Eurasian foods made from common millet are classified into four processing methods: grain, coarse-ground flour, fine flour, and drinks. Asian people cook boiled grain and porridge from the polished grains of non-glutinous varieties (Table 20). Especially, East Asians cook steamed grain and *mochi* (a kind of cake) from the polished grains of glutinous varieties and ferment alcoholic drinks from polished grains of both non-glutinous and glutinous varieties. Inner Mongolians drink daily milk tea with roasted grains (Figure. 30a). Uzbeks top *non* (a kind of bread) with colored grains (Figure 30b) and cook milk porridge from non-glutinous varieties for lunch at a nursery school

(Figure 30c). Europeans cook milk porridge from coarse-ground flour, bread from fine flour, and ferment non-alcoholic drinks from polished grains of only non-glutinous varieties. Based on the endosperm starch in seed grains, the varieties were divided into two glutinous or non-glutinous categories. The distribution of glutinous varieties of common millet and *Setaria italica* were restricted to eastern Asia. On the contrary, the geographical distribution of phenol color reaction to seed coats in *S. italica* was very similar to that of *Oryza sativa*, but the distribution in common millet was different from the trends in *S. italica* and *O. sativa* (Sakamoto 1982, Kawase and Sakamoto 1982, Kimata and Negishi 2002).

Table 20. Iodo-starch reaction of endosperm (waxy or non waxy)

Localitty	No. of strains	Color reaction: No. of strains (%)			
		red broun (awaxy)	grape (medium)	blue (non waxy)	undicided
Japan	132				
Hokkaido	16	1 (6.3)	15 (93.7)		
Honshu	57	33(57.9)	21(36.8)	3(5.3)	
Shikoku	30	23(76.7)	7(23.3)		
kyushu	9	6(66.7)	3(33.3)		
South West Islands	20	13(68.4)	6(31.6)		1
East Asia	39				
Korea	23	11(50.0)	5(22.7)	6(27.3)	1
China	10	6(60.0)	1(10.0)	3(30.0)	
Mongolia	6			6(100)	
South Asia	90			90(100)	
West Asia	26		1(3.8)	25(96.2)	
Former Soviet Union	78				
Central Asia	12			12(100)	
Others	66	1(1.5)	2(3.0)	63(95.5)	
Europe	43		1(2.4)	41(97.6)	1
Africa	2			2	
North America	1			1	
Total	411	94(23.0)	62(15.2)	252(61.8)	3

Kimata & Negishi 2002 modified

The four types of local varieties of common millet were categorized by the composition of the minor fatty acids arachidic, behenic, and eicosapentaenoic acid. If the ancestral prototype was the weedy AE type containing arachidic and eicosapentaenoic acids, the AB type (arachidic and behenic acid) may have been bred both in Europe and Asia, while the ABE (all three fatty acids) and O (no fatty acids) types may have originated around Central Asia and then spread to both Europe and Asia (Kimata et al. 2007).

Table 21. Foods made from common millet around Eurasia

Locality	glutinous/non-glutinous	grain				coarse-ground flour	ground flour			drinks	
		boiled	steamed	porridge	*mochi*	porridge	dumpling	gruel	bread	non-alcohol	alcohol
Japan	non-glutinous	○		○			○	○			
	glutinous		○		○		○				○
Korea	non-glutinous	○									
	glutinous		○		○						○
China	non-glutinous	○		○					○		○
	glutinous		○		○				○		○
Taiwan	non-glutinous	○									
	glutinous		○		○		○				○
Bataan Isles	non-glutinous					○					
Halmahera	non-glutinous					○					
India	non-glutinous	○				○		○	○		
Pakistan	non-glutinous	○							○		
Afghanistan	non-glutinous					○	○		○		
Uzbekistan	non-glutinous					○			○		
Kazakhstan	non-glutinous					○					
Caucasia	non-glutinous					○				○	
Turkey	non-glutinous					○					
Ukraine	non-glutinous					○				○	
Bulgaria	non-glutinous					○				○	
Romania	non-glutinous					○			○		
Germany	non-glutinous					○					
Belgium	non-glutinous					○					
Italy	non-glutinous					○					

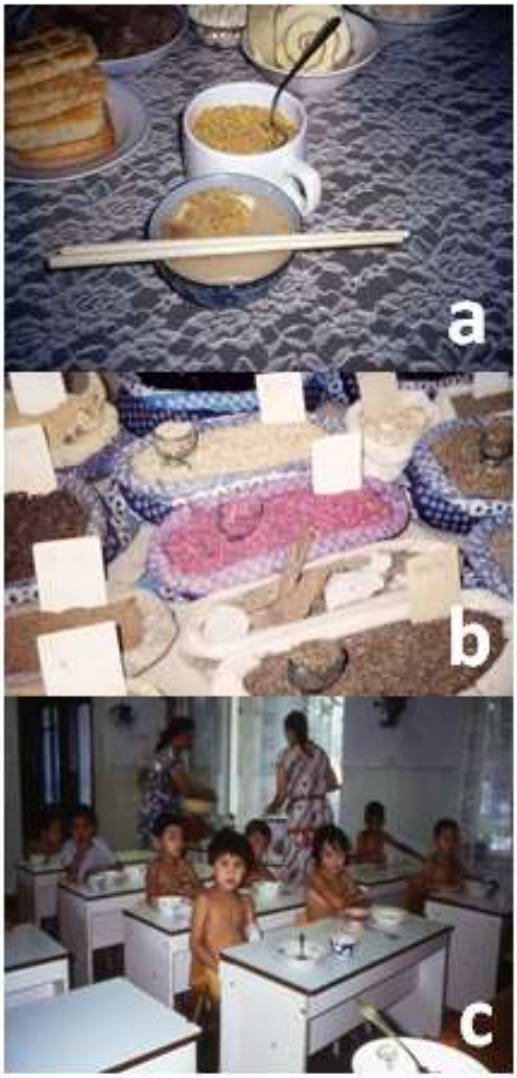


Figure 30. Foods from common millet in Uzbekistan and Inner Mongolia.

a, milk tea with roasted grains in Inner Mongolia; b, colored grains for a topping of bread in Uzbekistan; c, milk porridge for healthful lunch at a nursery school in Uzbekistan.

Vernacular names of *P. miliaceum*

The linguistic data are as follows (Table 3). Prefixes for the word for "common millet" were mainly "*ki-*," "*che-*," "*va-*," or "*ba-*" in East and South Asia, but several variations were noted in China. The prefixes were widely diverse in Central Asia and the mountainous area of Pakistan. It was mainly "*d-*" in western Asia and Egypt. There were also many European prefixes, including "*mi-*" and "*proso*." Because the vernacular names of common millet were remarkably diverse around all Eurasia, this indicates that the crop was domesticated and/or broadly dispersed starting in a very ancient period. However, common millet is called "*cheena*," "*chiena*," or "*chin*" in the Indian subcontinent. Based on the Farming/Language Dispersal Hypothesis (Bellwood and Renfrew 2002), these vernacular names might be derived from China and "Qin" (an ancient Chinese Empire), indicating that common millet was dispersed from China to the Indian subcontinent through a route via Nepal.

Table 22. Vernacular names of *P. miliaceum* around Eurasia

Region	Country	Modern name	Ancient name
East Asia			
	China	chi, huangmi, nianmi, shu, shuzi,	shu
	Inner Mongolia	horei bata	
	Korea	kijan	
	Japan	inakibi, kibi, kokibi	kimi, shipshi-kepp
Central Asia			
	Kazakhstan	psheno	
	Afghanistan	arzan	
South Asia			
	Pakistan		
	North	bau, cheena, chiena, olean, onu	
	South	tzetze	
	India		
	North	charai, cheena, chin, china, sawan, worga	unoo, vreelib-heda, vreehib-heda
	South	baragu, cheena, , katacuny, pani baragu, tane, variga, varagu, wari	
	Nepal	china	
	Sri Lanka	mene'ri	
West Asia			
	Arabia	dokhn, kosaejb, kosjaejb	
	Turkey	dari, kundari	
	Israel	dokhan	
Africa			
	Egypt	dokhn	
Europe			
	Greece		kegchros
	Hungary	ko″les	
	Russia	proso	
	Poland	proso	
	Croatia	proso	
	Lithuania		sora
	Netherlands	gierst	
	Germany	rispen hirse	
	Italy	milium	miglio
	Spain	mijo commun	
	France	millet commun	
	United Kingdom	common millet	mill

cf. Kawase 1991, Sakamoto 1986, and many dictionaries.

Domestication process and dispersal of common millet

The botanical origin, domestication, and geographical dispersal of common millet were discussed and then integrated through the results mentioned above. The following working hypothesis might well-explain the place of origin and dispersal of common millet with respect to recent archaeological contributions (e.g., Fuller et al. 2001, Hunt and Jones 2006, Jones 2004, Nesbitt 2005). This hypothesis is supported by the crossability among varieties in Eurasia and the geographical variation of several genetic characteristics (Table 5), although this needs further detailed study, especially the phylogeny of common millet and its close relatives. The early domestication process began in Central Asia and then progressed with a continuous process of dispersal toward China. The domestic type then dispersed from Central Asia to South Asia, directly to Europe, and indirectly to southeastern Europe via West Asia. On the other hand, this grain crop might have dispersed from China to Japan and Southeast Asia. The ancient farmers who had

cultivated barley and wheat in the Near East area had not necessarily accepted common millet. However, the nomads who had moved around the Eurasian steppe had gladly accepted the millet as the food source, the same as the present-day Mongolian herdsmen, because of its early maturation within the short summer season and its value as fodder for the livestock. They dispersed common millet from Central Asia to China and Europe. Common millet might have dispersed faster to Europe in an east/west direction at similar latitudes than to southeastern Europe in a south/north direction across different latitudes. It matured early in summer, but barley and wheat grew slowly in winter.

The traditional varieties cultivated by the Ainu people in Hokkaido, Japan are similar to the varieties from North China and Mongolia in their panicle type and the duration to flowering, while the other Japanese varieties are similar to the varieties from Korea and Nepal in their panicle type and stigma color (Kimata et al. 1986). The same large variability in lemma color and panicle type was shown in varieties from both the former USSR and Europe. Indian and West Asian varieties had very large variation in many characteristics (Figure 3 and Table 4).

As compared with the other varieties through Eurasia, the varieties around Afghanistan, Pakistan, India, and Central Asia had a large diversity of characteristics, including sparse panicles and many tillers. The geographical distribution of characteristics was useful information including the biocultural diversity, particularly foods and vernacular names (Tables 2 and 3) to reconstruct the domestication process and dispersal routes (Kimata 2015c).

An ancestral form of common millet might have had early maturation, remarkable grain shattering, sparse panicles, small grains, many tillers, pale brown lemmas, white stigmas, glabrous uppermost internodes, and non-glutinous starch. Usually, the domestic form of cereals has fewer productive tillers than wild forms. Many varieties from Central Asia and the Indian subcontinent show many of the ancestral characteristics. There is only a little information on the mimic weed type associated with the domestic type of common millet (Sakamoto 1988, Scholz and Mikolāš 1991), but several weed types with remarkable grain shattering have been found in Pakistan, Uzbekistan, and Kazakhstan (Kimata 1994, 1997). These seeds were mixed with those of the domestic type. Because the varieties around Central Asia show large variation and their related weedy subspecies still grow today, this area is appropriate to be the place where common millet had been domesticated. Moreover, the weed types were classified into two subspecies, *ruderale* and *agricolum*, and a crop-like weedy biotype escaped from the domestic type. It would seem that *ruderale* was an ancestor, while *agricolum* became a weed by hybridization between these two subspecies.

Common millet was domesticated from a wild variety of *P. miliaceum* subsp. *ruderale* in Central Asia including the northern mountains of Afghanistan and Pakistan, especially from the Aral Sea to the Southwest Tien Shan Mountains. It was dispersed both eastward to China and westward to Europe, and both southward to the Indian subcontinent (de Wet 1995) and northward to Siberia by nomadic groups since the Neolithic era. Moreover, when the Mongolian army invaded Europe in the thirteenth century, they carried with them common millet (Carpine 1246). It suggests the dispersal of common millet by Mongolian that a few Chinese varieties are mingled with European varieties in the clusters of morphological characteristics (Figure 3) and AFLP markers (Figure 5). Additionally, the traditional varieties cultivated by the *Ainu* people in Japan (Hokkaido) are similar to the varieties from North China and Mongolia in their panicle type and early duration to flowering, while the other Japanese varieties are similar to the varieties from Korea and Nepal in their panicle

type, stigma color, and phenol reaction of young lemmas (Kimata et al. 1986, Kimata and Negishi 2002). A northern route from North China into Hokkaido is suggested by the fact that PC57-2 (Hokkaido, Japan) made fertile hybrids among the testers from Central Asia, India, and Japan.

An ancestor of common millet may have been a wild type of *P. miliaceum* subsp. *ruderale*. The early domestication process began around Central Asia and then progressed in a continuous dispersal process toward China. Furthermore, the domestic type dispersed from Central Asia to South Asia, directly to Europe, and indirectly to southeastern Europe via West Asia.

Common millet (*Panicum miliaceum* L.) was the most important grain crop in Eurasian civilization for several thousand years starting from the Neolithic era. It is still cultivated and has various uses around the world. Although it is one of the oldest domesticated plants in Eurasia, the ancestral plant and place of origin have yet to be definitively determined. A series of studies was started based on the plant's morphological and ecological characteristics, followed by studies of its genetic characteristics and secondary compounds, to elucidate its domestication process and dispersal in Eurasia. Accessions (650 local varieties obtained from local famers) and herbarium specimens collected by field surveys were used for observations and experiments on morphological and ecological characteristics, crossability, amplified fragment length polymorphism of total DNA, phenol and iodine color reactions of seeds, fatty acid component in seeds, traditional food styles, and archeolinguistic data. The botanical origin, domestication process, and geographical dispersal of common millet are discussed and then integrated through the characteristics mentioned above. In conclusion, common millet was domesticated from a wild population of *P. miliaceum* subsp. *ruderale* in Central Asia, specifically from the Aral Sea to the Southwest Tien Shan Mountains. Since the Neolithic era, the millet has been dispersed eastward to China, westward to Europe, southward to the Indian subcontinent, and northward to Siberia by nomadic groups.

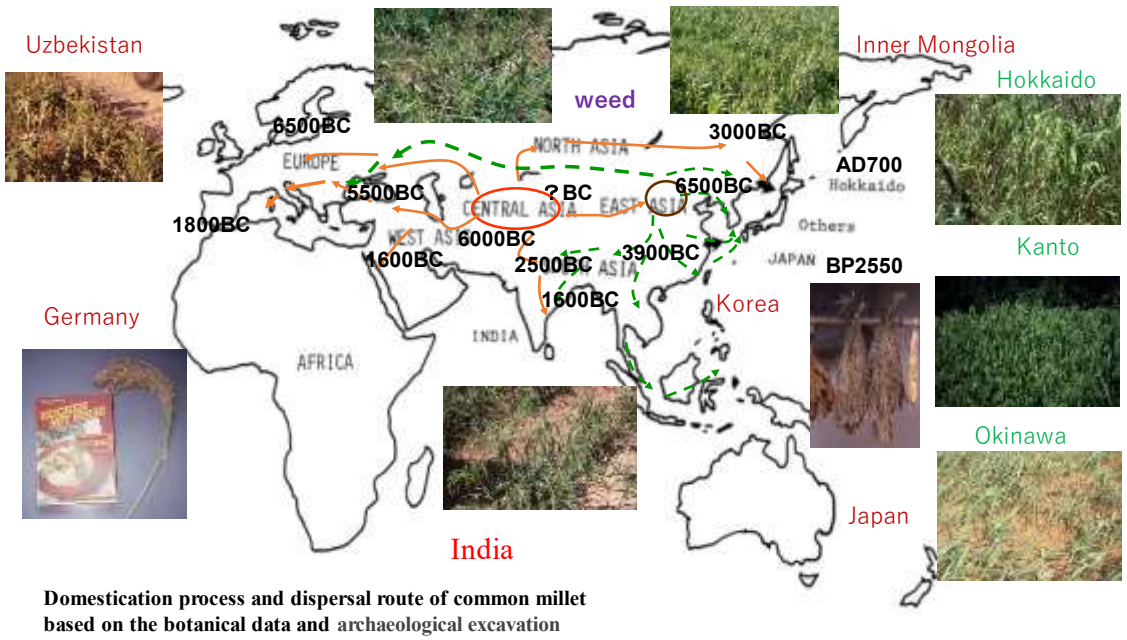


Figure 31. Dispersal routes of common millet through the Eurasia

Chapter 5　Domestication Process of Millets in Indian Subcontinent

The Indian subcontinent is the most interesting and important region for millet research. The numerous farmers had grown many kinds of millet species, and also numerous people had used and eaten much volume of millets since ancient age. This subcontinent is the most excellent region, in order to our study on the domestication process of millet. However, the researchers of anthropology and ethnology have not a strong interest in the millet domesticated in the Indian subcontinent.

The most excellent researcher, Kobayashi, H. had conducted this study on the secondary crop, unfortunately, but he had gotten malaria in Africa, then had passed away in 1994. After that I have taken over his study, because of respect to the closest friend for travelling with him in India. Also, the capable coordinator, Seetharam, A. had joined and supported our collaborative research in the Indian subcontinent. He had passed away in 2025. We really appreciate his kindness.

Field research in the Indian subcontinent

I had participated six times in expeditions for millet research and collected numerous accessions of millets and their relative species, with information on their agricultural complex, from hundreds of farmers in their villages and fields (Table 23). He mainly visited the southern foot of the Himalayas and Western and Eastern Ghats in and around the Indian subcontinent between 1983 and 2001. The research team used many means of transportation, such as car, train, airplane, and their feet, for frequent field trips (Figure. 31). Particularly, the trips extended widely over Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Telangana, Maharashtra, Madhya Pradesh, Orissa, Chhattisgarh, Jharkhand, West Bengal, Bihar, Uttar Pradesh, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir in India and the North-West Frontier in Pakistan and Eastern Nepal.

Table 23. Expeditions of millet research in the Indian subcontinent during 1983 to 2001.

Year (month)	Locality	Research Team
1983.9–11	Nepal, India (Hariana)	The Japanese Scientific Expedition for Nepalese Agricultural Research
1985.9–11	Pakistan (Northwest province), India (Karnataka, Andhra Pradesh, and Tami Nadu)	Kyoto University Scientific Expedition to the Indian Subcontinent
1987.9–11	India (Jammu and Kashmir, West Bengal, Orissa, and Assam), Pakistan (Sind)	Kyoto University Scientific Expedition to the Indian Subcontinent
1989.9–10	Pakistan (Azad Kashmir), India (Karnataka, Madhya Pradesh, and Maharashtra)	Kyoto University Scientific Expedition to the Indian Subcontinent
1996.9～97.6	India (Karnataka, Andhra Pradesh, Tamil Nadu, Orissa, Himachal Pradesh, and Utter Pradesh)	Research abroad supported by Japanese Government, University of Agricultural Sciences at Bangalore
2001.9–10	India (Karnataka and Orissa)	Tokyo Gakugei University Scientific Expedition to the Indian Subcontinent

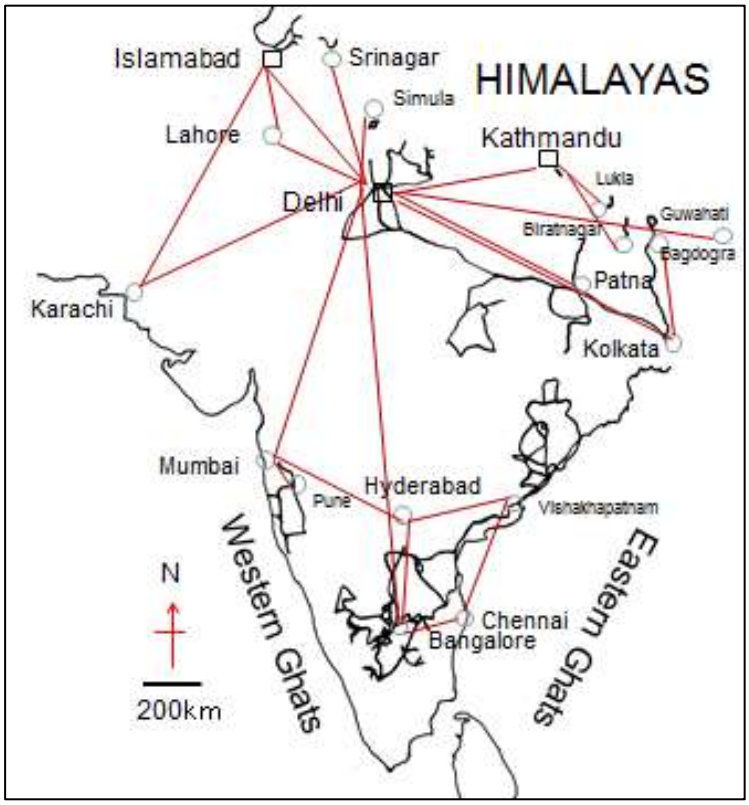


Figure 31. Expedition routes in the Himalayas, Western Ghats and Eastern Ghats.

Grain crops grown in the Indian subcontinent

The Indian subcontinent is a wonderland for studying the domestication process of grain crops as shown in Table 24. Several species of millet are domesticated in this region. The grain crops cultivated in this subcontinent are classified into the following four groups on the basis of geographical origin: (I) African, *Eleusine coracana* (L.) Gaertn., *Pennisetum glaucum* (L.) R. Br., and *Sorghum bicolor* Moench; (II) Mediterranean, *Hordeum vulgare* L. and *Triticum* spp.; (III) Asian, including four subgroups, (a) *Panicum miliaceum* L. and *Setaria italica* (L.) P. Beauv., (b) *Coix lacryma-jobi* L. var. *ma-yuen* (Roman.) Stapf. and *Oryza sativa* L., (c) *Echinochloa frumentacea* (Roxb.) Link, *Panicum sumatrense* Poth., *Paspalum scrobiculatum* L., *Digitaria cruciata* (Nees) A. Camus., *Setaria pumila* (Poir.) Roem. & Schult, and *Brachiaria ramosa* (L.) Stapf.; and (d)

Southwestern China, *Fagopyrum esculentum* Moench, *Fagopyrum tataricum* (L.) Gaertn.; and (IV) New World, *Zea mays* L., including *Amaranthus hypocondriacus* L., *Amaranthus caudatus* L., and *Chenopodium quinoa* Willd. These four cereals and pseudocereal groups accompanied by agricultural complexes have been introduced several times during prehistoric and historic ages from many regions into the subcontinent.

Many species of millet are still grown by numerous farmers in the Indian subcontinent. These species are divided into three groups on the basis of place of origin: (1) Asia, including the indigenous Indian subcontinent, Central Asia, Southeast Asia, and Tibet; (2) Africa; and (3) the New World. The following seven species of Asian millet were introduced from Central Asia, Southeast Asia, and Tibet: *Panicum miliaceum*, *Setaria italica*, *Coix lacryma-jobi* var. *ma-yuen*, *Fagophyrum esculentum*, and *Fagophyrum tartaricum.* The African millet species are *Eleusin. coracana*, *Sorghum bicolor*, and *Pennisetum glaucum.* These species were introduced via the Arabian peninsula in about 2000 BC (Sakamoto 1987, Ohnishi 1998). The New World pseudocereals are *Amaranthus caudatus*, *Amaranthus hypocondriacus*, and *Chenopodum quinoa*, and they were introduced in 19th century (Sauer 1976).

Table 24. Grain crops grown in the Indian subcontinent

Geographical origin Scientific name	Japanese name	Indian name	Chromosome number	Growth habit	Botanical origin
Africa					
Sorghum bicolor	morokoshi	jowar	2n=20 (2x)	annual	*S. bicolor* var. *verticilliflorum*
Pennisetum americanum	toujinn-bie	bajra	2n=14 (2x)	annual	*P. violaceum*
Eleusine coracana	shikoku-bie	ragi	2n=36 (4x)	annual	*E. coracana* var. *africana*
Asia					
1. India					
Panicum sumatrense		samai	2n=36 (4x)	annual	*P. sumatrense* ssp. *psilopodium*
Paspalum scrobiculatum		kodo	2n=40 (4x)	perennial	wild
Echinochloa flumentacea	indo-bie	jangora	2n=54 (6x)	annual	*E. colona*
Brachiaria ramosa		korne		annual	wild
Setaria pumila	kin-enokoro	kolati		annual	wild
Digitaria crusiata		raishan		annual	wild
2. South-eastern Asia					
Coix lacryma-jobi var. *ma-yuen*	hatomugi		2n=20 (2x)	perennial	*C. lacryma-jobi* var. *lacryma-jobi*
3. Central Asia					
Setaria italica	awa	thenai	2n=18 (2x)	annual	*S. italica* ssp. *viridis*
Panicum miliaceum	kibi	cheena	2n=36 (4x)	annual	*P. milliaceum* ssp. *ruderale*
4. South-western Asia					
Fagopyrum esculentum	soba		2n=16 (2x)	annual	*Fagopyrum esculentum* ssp. *ancestralis*
Fagopyrum tartaricum	dattan-soba		2n=16 (2x)	annual	*Fagopyrum tartaricum* ssp. *potanini*
New world					
Amaranthus hypocondriacus	sen-ninkoku		2n=32, 34 (2x)	annual	*A. cruentus (A. hybridus)*
Amaranthus caudatus	himogeitou		2n=32, 34 (2x)	annual	*A. cruentus (A. hybridus)*
Chenopodium quinoa	kinoa		2n=36 (4x)	annual	*C. quinoa* ssp. *milleanum*

Indigenous millet species have been domesticated in the Indian subcontinent for about 3500 years (Fuller 2002). These millet species are *Echinochloa furumentacea*, *Panicum sumatrense*, *Paspalum scrobiculatum*, *Brachiaria ramosa*, *Setaria pumila*, *Digitaria cruciata*, and *Digitaria sanguinalis*. The former three species seemed to be secondary in origin through mimic and/or companion weeds with rain-fed paddy and upland rice in Eastern India. The next two species, *Brachiaria ramosa* and *Setaria pumila*, were domesticated as a secondary crop associated with the

other millet species via their mimic/companion weed types in Southern India. *Digitaria cruciata* was domesticated in the late 19th century by Kashi natives in Meghalaya, and it is cultivated in the Kashi Hills (Singh and Arora 1972). Unfortunately, *Digitaria sanguinalis* has disappeared, and its origin is unclear. A domesticated plant is always accompanied by the basic agricultural complex, which includes cultivation practices, processing, cookery, religious use, vernacular names, and other aspects.

A domestication centre for millet covers the Eastern Ghats and Southern Deccan Plateau on the basis of field observation, experimental results, linguistic sources, and archaeological data. Although this process is quite complicated among millet and its relatives, it is very effective for understanding domestication by a secondary origin via an insurance crop, a mimic companion weed, and weed types. The domestication process indicates the importance of the weed–crop complex and basic agricultural complexes as a plant–man symbiosis. Moreover, it is obvious that several words of the old Indo-Aryan and Dravidian languages are related to the vernacular names of millets. Consequently, *Brachiaria ramosa* and *Setaria pumila* are called 'tertiary crops', which means they are double secondary crops for other millet species and upland rice. The order of first occurrence for millet species in historical sites generally supports this evolutionary process.

Ancient farmers had originally domesticated six species of millet from the relative weed species in India. Then, these plants were distributed over the Indian subcontinent and neighbouring areas.

Panicum sumatrense (*samai*) is an annual plant (2n = 36, tetraploid) derived from *Panicum sumatrense* ssp. *psilopodium* (Figure 32a). *Paspalum scurobiculatum* (*kodo*) is a perennial plant (2n = 40, tetraploid, Figure 32b). *Echinochloa furumentacea* (*jangora*) is an annual plant (2n = 54, hexaploid, Figure 33c) derived from the relative weed *Echinochloa colona*. *Brachiaria ramosa* (*korne*) and *Setaria pumila* (*kolati*) are annual plants (Figure 32d and 32e). These plants are secondary crops domesticated from their relative weeds in paddy fields. This will be discussed in detail below. *Digitaria cruciata* (*raishan*) is an annual plant derived from the relative weed grown in maize or vegetable fields (Singh and Arora 1972). In addition, *Oryza rufipogon* Griff. (wild rice) is used as an offering for gods and goddesses during festivals. It grows in ponds and irrigation canals near paddy fields (Figure 32f).

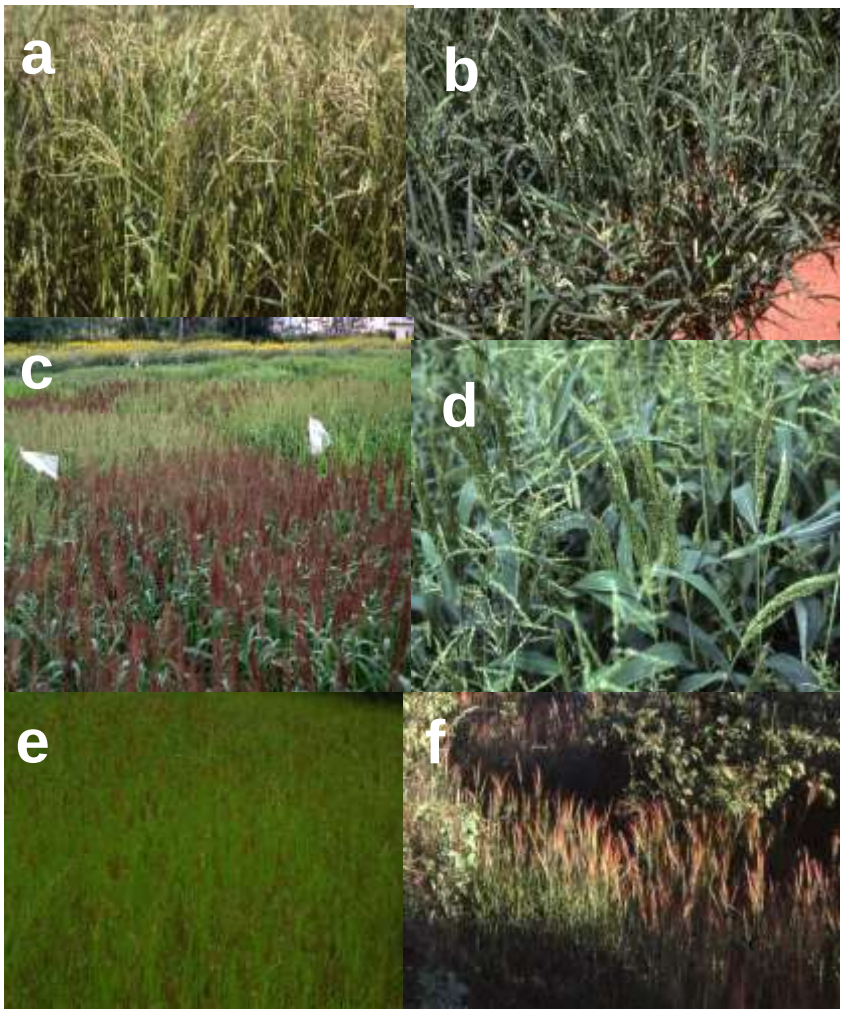


Figure 32. Five species of millet domesticated in the Indian subcontinent and wild rice: a, *Panicum sumatrense*; b, *Paspalum scrobiculatum*; c, *Echinochloa frumentacea*; d, *Brachiaria ramosa*; e, *Setaria pumila*; and f, *Oryza rufipogon* in the irrigation canal.

Indian farmers introduced six species of millet from Africa via the Arabian Peninsula, Central Asia through the Himalayas, and South-Eastern Asia via Assam in the Indian subcontinent during the Indus Civilization Age or before the dawn of history.

Sorghum bicolor (*jowar*) is an annual plant (2n = 20, diploid, Figure 33a) derived from *Sorghum bicolor* var. *verticilliflorum* in Eastern Africa. *Pennisetum glaucum* (*bajra*) is an annual plant (2n = 14, diploid, Figure 33b) domesticated from *Pennisetum violaceum* in Africa. *Eleusine coracana* (*ragi*) is an annual plant (2n = 36, tetraploid, Figure 33c) domesticated from *Eleusine coracana* var. *africana* in Eastern Africa.

Setaria italica (*thenai*) is an annual plant (2n = 18, diploid, Figure 33d) derived from *Setaria viridis*, a cosmopolitan weed in Central Asia. *Panicum miliaceum* (*cheena*) is an annual plant (2n = 36, tetraploid, Figure 33e) domesticated from *Panicum miliaceum* ssp. *ruderale* in Central Asia. *Coix lacryma-jobi* var. *ma-yuen* is a perennial plant (2n = 20, diploid) domesticated from *Coix lacryma-jobi* var. *lacryma-jobi* in South-Eastern Asia. These millet species are mostly grown by

mixed cropping or intercropping, for example, *Setaria italica* is grown and mixed with *Glycine max* (Leguminosae), as shown in Figure 33f.

Moreover, five species of pseudocereals are grown in the Indian subcontinent. *Fagophylum esculentum* and *Fagophylum tartaricum* (both annual, 2n = 16, diploid) were introduced from Tibet. Recently, *Amaranthus caudatus*, *Amaranthus hypocondriacus* (both annual, 2n = 32 or 34, diploid), and *Chenopodeum quinoa* (annual, 2n = 36, tetraploid) were dispersed from the New World.

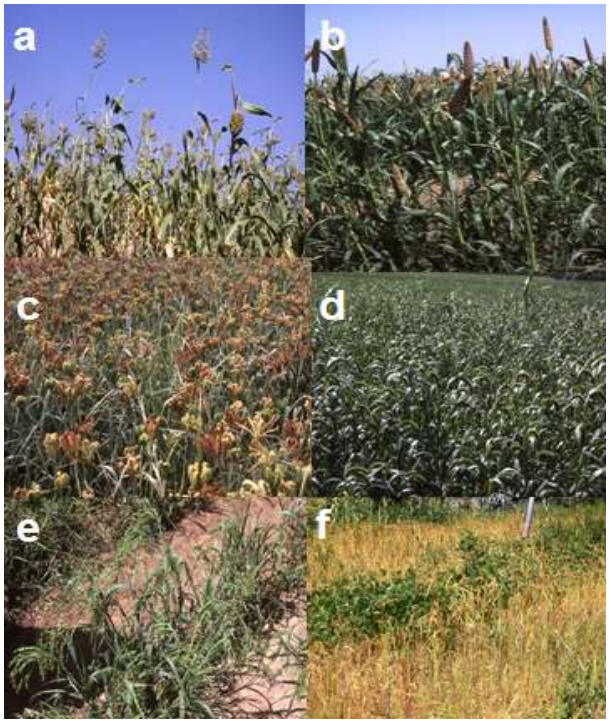


Figure 33. Five species of millet introduced into the Indian subcontinent and a field of inter-cropping with *Setaria italica* and *Grycine max*:

a, Sorghum bicolor; b, Pennisetum glaucum; c, *Eleusine coracana*; d, *Setaria italica*; e, *Panicum miliaceum*; and f, an inter-cropping field.

Many species of millet cultivated in the Indian subcontinent

Many species of millet are still grown by numerous farmers in the Indian subcontinent. These species are divided into three groups on the basis of place of origin: (1) Asia, including the indigenous Indian subcontinent, Central Asia, Southeast Asia, and Tibet; (2) Africa; and (3) the New World (Table 1). The following seven species of Asian millet were introduced from Central Asia, Southeast Asia, and Tibet: *Panicum miliaceum*, *Setaria italica*, *Coix lacryma-jobi* var. *ma-yuen*, *Fagophyrum esculentum*, and *Fagophyrum tartaricum.* The African millet species are *Eleusin. coracana*, *Sorghum bicolor*, and *Pennisetum glaucum.* These species were introduced via the Arabian peninsula in about 2000 BC (Sakamoto 1987, Ohnishi 1998). The New World pseudocereals are *Amaranthus caudatus*, *Amaranthus hypocondriacus*, and *Chenopodum quinoa*, and they were introduced in 19th century (Sauer 1976).

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Paspalum scrobiculatum, *Brachiaria ramosa*, *Setaria pumila*, *Digitaria cruciata*, and *Digitaria sanguinalis*. The former three species seemed to be secondary in origin through mimic and/or companion weeds with rain-fed paddy and upland rice in Eastern India. The next two species, *Brachiaria ramosa* and *Setaria pumila*, were domesticated as a secondary crop associated with the other millet species via their mimic/companion weed types in Southern India. *Digitaria cruciata* was domesticated in the late 19th century by Kashi natives in Meghalaya, and it is cultivated in the Kashi Hills (Singh and Arora 1972). Unfortunately, *Digitaria sanguinalis* has disappeared, and its origin is unclear. A domesticated plant is always accompanied by the basic agricultural complex, which includes cultivation practices, processing, cookery, religious use, vernacular names, and other aspects.

A domestication centre for millet covers the Eastern Ghats and Southern Deccan Plateau on the basis of field observation, experimental results, linguistic sources, and archaeological data. Although this process is quite complicated among millet and its relatives, it is very effective for understanding domestication by a secondary origin via an insurance crop, a mimic companion weed, and weed types. The domestication process indicates the importance of the weed–crop complex and basic agricultural complexes as a plant–man symbiosis. Moreover, it is obvious that several words of the old Indo-Aryan and Dravidian languages are related to the vernacular names of millets. Consequently, *Brachiaria ramosa* and *Setaria pumila* are called 'tertiary crops', which means they are double secondary crops for other millet species and upland rice. The order of first occurrence for millet species in historical sites generally supports this evolutionary process.

This special issue is composed of studies on the agricultural complex, domestication process, and dispersal of millets, especially *Setaria pumila* (syn. *Setaria glauca*) and *Panicum milliaceum* and not major crops such as rice, wheat, barely, and maize, in the Indian subcontinent. *Setria pumila* has been dispersed in only a very limited area of the Deccan Plateau (Kimata 2015a, 2015b), while *Panicum milliaceum* has been dispersed throughout Eurasia (Kimata 2015d), including the Indian subcontinent, and recently North America and Australia. It is very fascinating from an environmental perspective of history and geography that the distribution patterns of *Setaria pumila* and *Panicum milliaceum* are remarkably different.

Morphological characteristics of *Setaria pumila*

Results of statistical analyses of partial correlation coefficients of the ten characteristics (number of tillers, plant height, length (pl) and width (pw) of spike, the ratio of pl/pw, length (fll) and width (flw) of flag leaf, the ratio of fll/flw, last internode diameter, and duration to flowering, are shown in Table 25. Those characteristics have been strongly affected by artificial selection during the domestication process. The controlled variables were seed size and seed shattering in this analysis. Statistical significance at the 1% level was found for the following results: ratio of length/width of flag leaf to plant height (-0.517); ratio of spike length/width (0.739), length of flag leaf (0.664), width of flag leaf (0.584), and diameter of last internode (0.716) to spike length; spike length (0.739) and length of flag leaf (0.704) to the ratio of spike length/width; spike length (0.664), the ratio of spike length/width (0.704), the ratio of length/width of the flag leaf (0.720), and the duration to flowering (-0.544) to length of flag leaf; spike length (0.584), the ratio of length/width of the flag leaf (-0.508), and the last internode diameter (0.882) to width of flag leaf; plant height (-

0.517), length of flag leaf (0.720), width of flag leaf (-0.508), and the duration to flowering (-0.561) to the ratio of length/width of the flag leaf; spike length (0.716) and width of flag leaf (0.882) to the last internode diameter; and length of flag leaf (-0.544) and the ratio of length/width of the flag leaf (-0.561) to the duration to flowering. There were no significant ($p < 0.01$) correlations between the number of tillers and the last internode diameter.

Table 25. Partial correlation coefficients of morphological characters in *Setaria pumila*

characteristics	tillers	plant height	spike length	spike width	sl/sw	flag leaf length	flag leaf width	fll/flw	first node diameter	dulation to flowering
tillers	1	−0.142	−0.055	−0.410*	0.221	0.166	−0.289	0.301	−0.239	−0.095
plant height	−0.142	1	0.256	−0.001	0.086	−0.224	0.404*	−0.517**	0.388*	0.211
spike length	−0.055	0.256	1	0.151	0.739**	0.664**	0.584**	0.166	0.716**	−0.242
spike width	−0.410*	−0.001	0.151	1	−0.455*	−0.132	0.254	−0.251	0.227	−0.091
sl/sw	0.221	0.086	0.739**	−0.455*	1	0.704**	0.172	0.488*	0.292	−0.227
flag leaf length	0.166	−0.224	0.664**	−0.132	0.704**	1	0.194	0.720**	0.311	−0.544**
flag leaf width	−0.289	0.404*	0.584**	0.254	0.172	0.194	1	−0.508**	0.882**	0.122
fll/flw	0.301	−0.517**	0.166	−0.251	0.488*	0.720**	−0.508**	1	−0.35	−0.561**
first node diameter	−0.239	0.388*	0.716**	0.227	0.292	0.311	0.882**	−0.35	1	0.171
dulation to flowering	−0.095	0.211	−0.242	−0.091	−0.227	−0.544**	0.122	−0.561**	0.171	1

Control variables: grain size、shattering

Cluster analysis of six morphological characteristics (number of tillers, plant height, spike length, length and width of flag leaf, and flag leaf length/width ratio) and the duration to flowering are illustrated in Figure 33. Using the Ward method, 60 accessions were categorized into three clusters and several sub-clusters. Cluster I contained sub-clusters Ia and Ib. Subcluster Ia (7 accessions) included weed type (W2); companion weed type (Ws1) from Maharashtra; companion weed type (Ws1); mimic companion weed type (medium, Ms2); and domestication type mixed with *samai* (*P. sumatrense*, Ds1) from Orissa. Sub-cluster Ib (5 accessions) included Ds5 from Andhra Pradesh (3), Karnataka (1), and Maharashtra (1). Cluster II contained sub-clusters IIa and IIb. Sub-cluster IIa (17 accessions) included: Ds1, Ms2, Mk4, Ws3, and W3 from Orissa; Dk2 from Karnataka; and Ws2 from Maharashtra. Sub-cluster IIb (2 accessions) included Ms1 and Ws1 from Orissa. Cluster III contained sub-clusters IIIa–c. Sub-cluster IIIa (1 accession) comprised W1 from Maharashtra. Sub-cluster IIIb (10 accessions) included Mk1, Ws6, Wk1, and W2 from Orissa. Sub-cluster IIIc (11 accessions) included Ds1, Dk1, Ms1, Mk2, Mp3, Ws1, and W1 from Orissa, and W1 from Maharashtra. The "W" type of *S. pumila* was distributed around the Indian Subcontinent as a cosmopolitan weed.

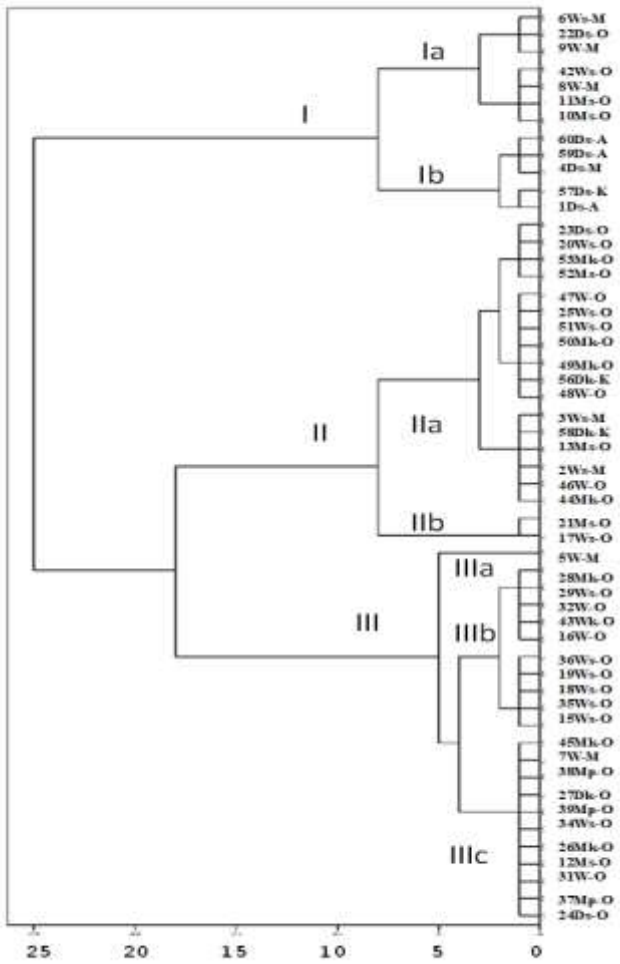


Figure 33. Cluster analysis of six morphological characteristics

Species component of millet and weed grown in four cropping fields (investigation sites)

The species ratio composition of each mixed cropping field was variable annually, according to some field conditions such as summer precipitation. At the early growing stage, it was very difficult to recognize morphological differences from each other in a set of plant species collected from the same cropping field. The inter- and intra-specific mimic variation had occurred not only in the morphological characteristics e.g., plant height, leaf size and number of tillers, but also in the ecological ones, e.g., seed germination pattern, seed color, and leaf sheath color. It was clear that the leaf sheath color of *P. sumatrense* and *Pas. scrobiculatum* (Sub-cluster IIa) was mimicry related to that of *S. pumila* (Cluster I). The glume color of *S. pumila* was also mimicry of the glume of *P. sumatrense*. The domestication process and dispersal of *S. pumila* has developed by means of elaborate mimicry in several characteristics of other crops to itself.

The species components (per m²) of four millet cultivation fields are shown in Table 25. At site 1, the percentages of *P. sumatrense*, *S. pumila,* and weed *Brachiaria* sp. were 59%, 33%, and 8%, respectively, while at the nearby site 2, the percentages were 25%, 74%, and trace. At site 3, a single stand of *E. coracana*, and at site 4, a single stand of *P. sumatrense*, the weed type of *S. pumila*, had invaded significantly, but represented only 3–5% into both cropping fields.

Table 26. Component species per m^2 of investigation site

Site no.	Locality	*Panicum sumatrense*	*Setaria pumila*	*Eleusine coracana*	*Brachiaria* sp.	*Digitaria* sp.	Total
Site 1	01-10-8-2 (805m alt.) Cittoor, Andhra Pradesh						
	No. of plants	163.5	90.75	0	22	0.25	276.5
	s.d.	76.43	36.48		24.99	0.5	75.54
	Range	78-264	55-141		0-56	0-1	191-355
	%	59.13	32.82	0	7.96	0.09	100
	Highest plant (cm)	77.38	66.88				
	s.d.	7.63	10.17				
Site 2	01-10-9-1 (690m alt.), Cittoor, Andhra Pradesh						
	No. of plants	105.5	312.25	0	0.75	1	419.5
	s.d.	68.83	60.91		0.5	0.82	68.98
	Range	30-172	240-368		0-1	0-2	352-517
	%	25.15	74.43	0	0.18	0.24	100
	Highest plant (cm)	76	68.25				
	s.d.	24.07	15.37				
Site 3	01-10-17-1 (855m alt.) Kundli, Orissa						
	No. of plants	1.75	1.5	42.25	0	0.25	45.75
	s.d.	0.96	1	6.85		0.5	26.12
	Range	1-3	1-3	34-50		0-1	46-101
	%	3.83	3.28	92.35	0	0.55	100
Site 4	01-10-19-3 (375m alt.), West Polehorebrdle, Orissa						
	No. of plants	40.5	2	0	0	0	45.75
	s.d.	8.23	1.63				20.59
	Range	30-50	0-4				40-86
	%	95.29	4.71	0	0	0	100

The domestication process of *Setaria pumila*

The domestication process of *S. pumila* may have passed through four steps as illustrated in Figure 34. The first step was a weed that had grown along roadsides and other unstable habitats and then invaded upland rice fields. The second step was an evolutionary process to obtain an agro-ecological niche out of weed status, using for fodder, in order to get the companion weed status growing in upland rice and some millet fields. The third step was a process of advancing from the mimic companion weed status to a semi-domesticated and insurance crop, used in case of famine, under mixed cropping with *Pas. scrobiculatum*, *E. coracana*, and *P. sumatrense*. The weed types after their invasion into upland rice and millet fields obtained mimicry associated with a particular crop, and made a close weed-crop complex under the severe weed control measures practiced by farmers. In the fourth and final step, the mimic companion weed forms were used not only a fodder source for cattle, but also as a supplementary grain to the main cereal species.

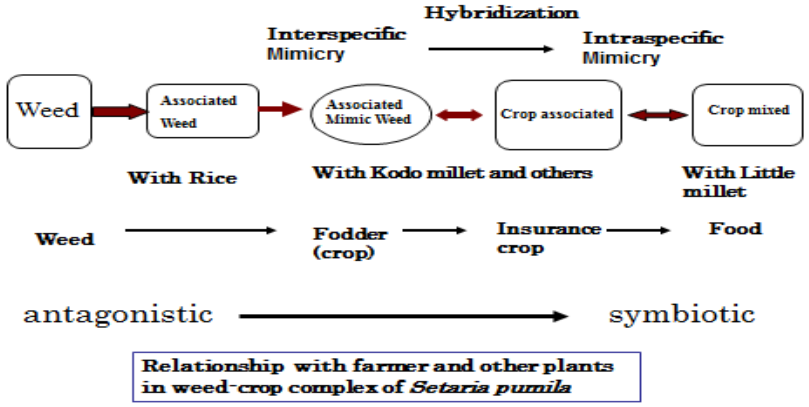


Figure 34. Domestication process of *Setaria pumila*

In the case of *S. pumila*, too strict weeding was avoided as a means of crop insurance in years of extreme drought in the Deccan Plateau. This possibly led to *S. pumila* growing taller with larger spikes and large seeds, accompanied with less shattering, and gradually progressing toward domestication. Actually, *S. pumila* has obtained mimic traits such as long leaf, a few tillers, and tall plant height in the field of *P. sumatrense.* The morphological and ecological characteristics of the 60 strains in *S. pumila* were very variable, as shown in Fig. 35. The plant height (cm) indicated a trend toward higher tallness in the domesticated type than in the weed type (Figure 35a). The number of tillers showed a slight reduction in the domesticated type compared to the weed type, excluding two exceptional strains (Figure 35b). The spike length (cm) clearly increased more in the domesticated type than in the weed type (Figure 35c). The duration to flowering (days) showed a bimodal pattern: early and late (Figure 35d). The early domesticated type was similar to the weed type, while the late domesticated type was similar to the mimic companion weed type mixed with other cereals. The length/width ratio of the flag leaf showed two trends, wide and slender, as shown in Figure 35e. The last internode diameter (mm) was clearly thick in the domesticated type than in the weed type (Figure 35f). The domesticated type mixed with *P. sumatrense* had a higher ratio than the others, which had a medium ratio. It was morphologically clear that spikes had become longer and the last internode diameter had become bolder in the domestication process.

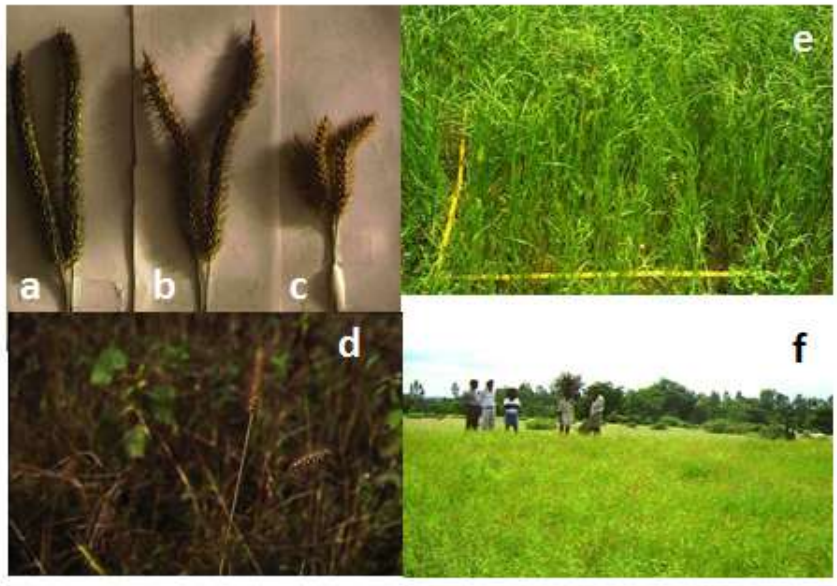


Figure 35. Panicle types of *Setaria pumila*:

a and b, domesticated types (Dk) mixed with *Paspalum scrobiculatum*; c, domesticated type (Ds) mixed with *Panicum sumatrense* and d, weed type shattering seed grains; e and f, cropping fields mixed with *Panicum sumatrense* and *Setaria pumila*: at Illur village near Chitoor in Andhara Pradesh.

Table 27. Characteristics of three types in domestication process of *P. sumatrense*

Characteristics	weed type in the field of *P. sumatrense*	mimic companion weed type to *Pas. scrobiculatum*	crop type mixed with *Pas. Scrobiculatum*
Seed shattering habit	remarkable	high	low
Spike length (cm)	6.1±0.6	10.4±0.4	11.1±1.3
Spikelet density (grains/cm)	29.0	30.5	33.9
Culm diameter (mm)	under 1	about 1	2
Bristle length (mm)	5.5, dense	6.5, dense	5, sparse
Grain length (mm)	2.0	2.5	3.0
Plant height (cm)	73.8±11.3	90.6±5.1	75.8±5.3
No. of tillers	40.1±10.6	20.0±3.5	43.0±9.7
Flag leaf length	17.1±3.3	22.8±4.5	31.0±4.6
Flag leaf width (cm)	0.5±0.1	0.8±0	1.1±0.1
Days to flowering	51	61	73

The crop types of *S. pumila* have broadly promoted the biocultural diversity through the mimicry of other grain crops. The crop type of *S. pumila* was always sown, harvested, and consumed together with *P. sumatrense*. Farmers called the mixed grains *tela samuru* (meaning white little millet) in Telugu. The proportion of grains purchased at a local market was 70% of *P. sumatrense* and 27% of *S. pumila*, respectively, in 1997 (Kimata et al. 2000). These authors are of the opinion that in severe drought, *S. pumila* provides a reasonable harvest while *P. sumatrense* might fail completely. This situation recommends the domestication process of secondary crops in other cereal fields against an arid climate. These crops are used to make six traditional foods in total, including *ganji* (thin flour porridge), *kheer* (sweet gruel) and *roti* (unleavened bread), as a supplementary ingredient as shown in Figure 36 (Kimata and Sakamoto 1992, Kimata et al. 2000).

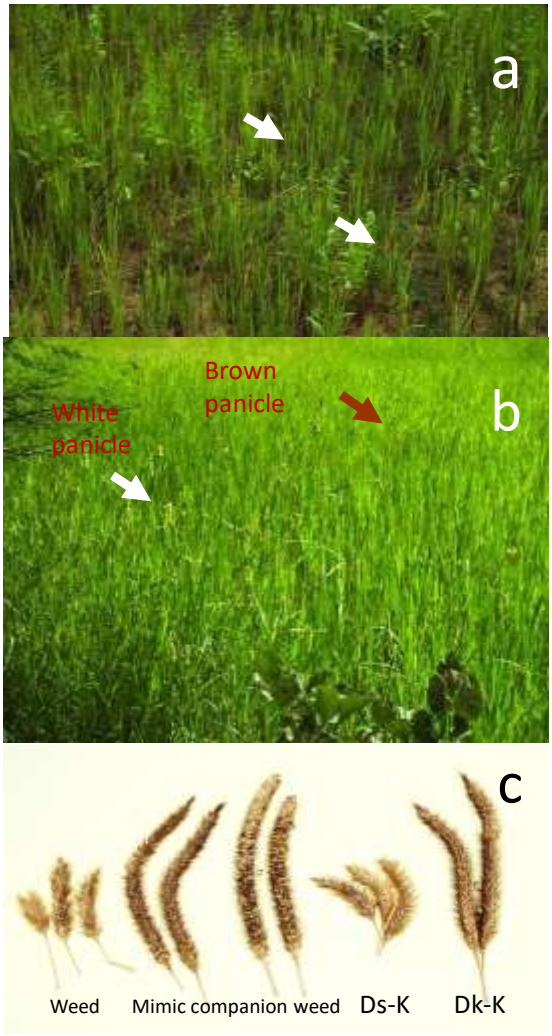


Figure 35. Fields of *Setaria pumila* mixed with *Pas. scrobiculatum* (a) and with *P. sumatrense* (b) in South India, and spikes of *S. pumila* (c):

weed; mimic companion weeds; Ds-K, domesticated type mixed with *P. sumatrense*, and Dk-K mixed with *Pas. scrobiculatum* in Karnataka.

It was very difficult for farmers to detect the difference among mimic companion weeds and domesticated types in sympatric fields during the early growing stage, because at this stage they resemble each other very closely. The seed germination of domesticated and annual plants was usually rapid and uniform, but that of *Pas. scrobiculatum*, perennial plants, and weeds was a little late and irregular.

At the same time, *S. pumila* diversified their traits in totality through hybridization among the types under natural and artificial selection in the severely arid environment. The mimic companion weeds were harvested together with other millet, and sown involuntarily again next season. In the third step, farmers changed their hostile weed control into a friendly one. Recently, during the fourth step, this situation was followed by mixed cropping. *S. pumila* is termed a tertiary crop in relation to its associated plants, which were secondary crops, such as *P. sumatrense, Pas. scrobiculatum*, with respect to rice.

Pas. scrobiculatum is perennial and the seed germination, tillering, and plant height elongation are usually slow. Therefore, *Pas. scrobiculatum* was distinguished relative to the other species. Among others, because these characters were synchronized to each other, it was very difficult to distinguish them, especially plant height and the number of leaves on main culm in the early growing stage. The domesticated type of *S. pumila* was adjustable to its associated mimic species in morphological characters, ecological traits in early growth, and plant pigmentation. It indicated mimicry of leaf and leaf sheath by way of color among *S. pumila*, *Pas. Scrobiculatum*, and *P. sumatrense*, but not *B. ramosa*. However, both leaf color of *S. pumila* (Ds) and *P. sumatrense* were the same green (371c~377c), while the leaf sheath color of *S. pumila* was reddish purple (198c~202c) in spite of a finding of green color (206c~207c) in *P. sumatrense* at site 8 in Andhra Pradesh. This case did not indicate mimicry of leaf sheath color.

Moreover, *S. pumila* has been domesticated as a tertiary crop, by way of the other millet species, to upland rice, because it has built up the strongest resistance to frequent droughts in the Deccan Plateau. The domesticated type of *S. pumila* is commonly cultivated in mixed stands mostly along with *P. sumatrense* in South India today, while the semi-domesticated crop and mimic companion weed types are not only grown with *P. sumatrense*, but also mainly with *Pas. scrobiculatum*, *E. coracana*, and upland rice in diverse agro-ecological niches in Orissa. The weed type of *S. pumila* grows widely through the India Subcontinent and tropical and temperate Northern Hemisphere. The various types have adapted to arid conditions and agro-ecological niches in the Deccan Plateau during their distribution from eastern humid areas to southern dry areas in the Indian subcontinent (Sehgal et al. 1992).

Seed color mimicry was found in the mixed grains of *P. sumatrense* and *S. pumila* at Illur village near Chittoor in Andhra Pradesh as shown in Figure 35a. The seed grains of *P. sumatrense* (Figure 35b) had a very similar pale brown color to the seed grains of *S. pumila* (Figure 35c), except for their black seed grains (Figure 35d). However, it was possible to distinguish the seed grains of *P. sumatrense* from those of *S. pumila* in detail, because of their glossy lemmata. Here, villagers have made three foods from *S. pumila*. They are boiled grain, *annamu*, flour porridge, *sankati* and semi-solid porridge, *uppitu*.

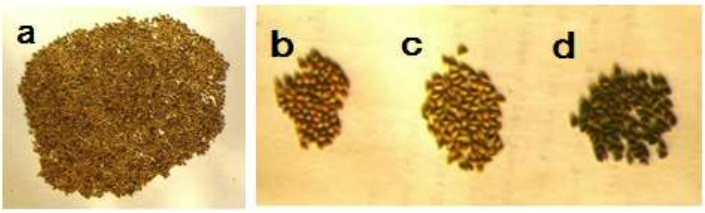


Figure 36. Seed mimicry of *S. pumila* to *P. sumatrense* and three foods made from their mixed grains at Jalaripali village, Andhra Pradesh:
a) mixed grains harvested and sold; after identified them, b) brown seeds of *P. sumatrense*, c) brown seeds and d) black seeds of *S. pumila*

Domestication process of *korati, Setaria pumila* on the basis of cluster analysis of

morphological characteristics and AFLP markers

The endemic landraces and related weeds were collected in field surveys around the Deccan in India since 1983, to explain the domestication process of *Setaria pumila* (Poir.) Roem. *et* Schult. (Poaceae) through its mimicry of other grain crops. The domestication process of *Setaria pumila* in relation to the weed-crop complex was comparatively investigated using statistical and AFLP analyses. It was clear on the basis of these results that the domestication process had progressed through the four stages according to geographical trends in morphological (artificial selection) and genetic variation (neutral DNA markers). Under the complex process, the 4 stages were as follows: weed, companion weed, mimic companion weed and domesticated type to the secondary crop. The paddy rice had dispersed from Assam, the humid east toward Deccan, the dry south in the Indian subcontinent. Several species of Indian millet were domesticated by local farmers as the secondary crop of rice along the climatic trend and dispersal route. In South India, one domesticated type of *S. pumila* was cultivated only in mixed stands mostly along *Panicum sumatrense.* Around Orissa, the other types and the related weeds were grown in the sympatric fields with *Paspalum scrobiculatum*, *Eleusine coracana*, and upland rice (*Oryza sativa*) in diverse agro-ecological niches. Therefore, *S. pumila* became exactly a tertiary crop to the other Indian millet (secondary crop to rice).

Humans have domesticated more than 30 grass species as grain crops in several parts of the world, possibly as long as 12,000 years ago. However, several species are threatened and, despite their potential food value in their native habitats, have disappeared or have not been extensively cultivated. This is because the yield and production of the three major crops: wheat, rice, and maize, have rapidly increased due to technological innovations in crop-improvement programs. Cultivation of other grain crops (e.g., millets) has decreased gradually during the 20th century, resulting in loss of genetic diversity of local varieties. It is currently necessary to recognize the value of these neglected species as exploitable and underutilized genetic resources that exhibit adaptability to stress-prone environments. In this paper, we focus on millet species, which are mostly C_4 plants, are early to mature, and can be cultivated under conditions of severe drought and harsh sunlight.

Small-scale farmers continue to cultivate a few useful local varieties of millet. These indigenous varieties are excellent materials for investigating crop evolution, particularly the origin and dispersal routes of domesticated plants. In the Indian subcontinent, a few millet species are still undergoing domestication (Kimata et al. 2000; Singh and Arora 1972). While crop evolution can be reconstructed mostly from botanical data, details on geographic origin and dispersal will become clear from information on the basic agricultural complex offered by local farmers. This basic agricultural complex consists mainly of cultivation, processing and cooking such as biocultural diversity.

Vavilov (1926) illustrated the domestication process from companion weeds associated with wheat to secondary crops in two genera, *Avena* and *Secale*. For example, *Secale cereale* L. acquired strong resistance to cold in high altitude or latitude areas, and subsequently was able to grow under more severe conditions than those under which wheat can grow. Kobayashi (1987, 1989) proposed an integrating model of the domestication of Indian millet (e.g. *P. sumatrense, Echinochloa frumentacea*) as a secondary crop from mimic companion weeds associated with *Oryza sativa* L. Farmers have manipulated the domestication process by selecting for desired growth, visual, and palatability traits, e.g. yield, early maturation, color, sugar content. However, -natural selection and

hybridization have occurred among closely related weeds during domestication.

The growing area of *O. sativa* expanded from wetlands to establish secondarily in uplands in the Indian subcontinent. In turn, weedy ancestral plants invaded paddy and upland rice fields. Local farmers subsequently domesticated *Panicum sumatrense* Roth. (little millet), *Paspalum scrobiculatum* L. (kodo millet), and *Echinochloa frumentacea* Link (Indian barnyard millet), as secondary crops, because these species demonstrated stronger resistance to drought than upland rice in Eastern India. Several additional species of millet were domesticated in this region: *Brachiaria ramosa* (L.) Stapf. (korne, browntop millet), *Digitaria cruciata* [Nees] A. Camus (raishan), and *Setaria pumila* (Poir.) Roem. & Schult. (korati, yellow foxtail millet; syn. *Setaria glauca* [L.] P. Beauv.) (Chandra and Koppar 1990; de Wet et al. 1983a, b, c).

Recently, archeological studies in the Indian subcontinent have provided useful data on the ancient history of various grains. Millet materials were identified from two archaeological levels in the Southern Neolithic chronology: Phase II (2300–1800 cal BC) and Phase III (1800-1200 cal BC). These materials were identified primarily as two species, *B. ramosa* and *Setaria verticillata* (bristly foxtail millet-grass). *S. pumila* was present in limited quantity, possibly gathered from the wild (Fuller et al. 2001). The first known occurrences of various cereals in the Harrappan Civilization are reported as wheat, barley, and oats in the Early phase (before 2600 BC); *Eleusine* sp. (problematic, *E. coracana*), *Setaria* sp., *Panicum* sp. in the Mature phase (2600-2000 BC); and *Paspalum* sp., *Echinochloa* sp., *Sorghum* sp., and *Pennisetum* sp. in the Late phase (more recent than 2000 BC) (Fuller and Madella 2000; Weber 1992).

Many new techniques using DNA markers, including SSR (simple sequence repeat), RAPD (random amplified polymorphic DNA), RFLP(restriction fragment length polymorphism), and AFLP (amplified fragment length polymorphism analysis), have been conducted for the genus *Setaria* (Benabdelmouna et al. 2001; d'Ennequin et al. 2000; Fukunaga et al. 2002; Lin et al. 2012). Intraspecific polymorphic variability revealed with RAPD and RFLP marker systems was negligible. AFLP has gained wide acceptance for enabling a high degree of resolution and reproducibility in genetic analysis (Lakshmi et al. 2002). AFLP has a number of other relevant applications and advantages for analysis of plant genomes in general. A large number of DNA loci can be assayed in each reaction, and a large number of fragments can be assayed with a relatively small number of primers. Intergeneric polymorphism revealed by AFLP markers was very high (94.4%). At inter-specific level, it was not significant enough AFLP analysis recorded a higher level of variation, 66.5%, between *Panicum miliaceum* and *P. sumatrense* (Bai et al. 1999). Information on intraspecific diversity and species relationships could form the basic foundation for further research on crop-improvement programs (Lakshmi et al. 2002).

GISH (Genomic in situ hybridization) patterns revealed that two diploid species (2n = 18), *S. viridis* and *S. italica*, bore genome AA and a tetraploid species (2n = 36), *S. verticillata*, had genome AABB. The genomic composition of *S. pumila* (polyploid species, 2n = 18, 36, 72) was unknown (Benabdelmouna et al. 2001).

S. pumila is a cosmopolitan weed distributed worldwide. This weed grows sympatrically on roadsides, uplands, and the levees of lowlands; four intraspecific types of *S. pumila* have been identified based on ecological habit: weed type (W), companion weed type accompanied by crops (Wx), mimic companion weed type accompanied by crops (Mx), and domesticated type mixed with

crops (Dx). Kimata et al. (2000 and unpublished) have shown the biocultural diversity of morphological and ecological characteristics in *S. pumila*, and the intraspecific differentiation of vernacular names (linguistic data). The present paper concerns the domestication process of *S. pumila*, which is related ecologically to weeds and several grain crops in the Indian subcontinent, based on cluster analysis of morphological characteristics and AFLP markers.

Materials and Methods

Many local varieties and relative weeds of *Setaria pumila* (Poir.) Roem. & Schult. (syn. *S. glauca* [L.] P. Beauv.) have been collected from the Indian subcontinent since 1983 in field surveys (Figure 37). Concentrated surveys were conducted in Karnataka, Andhra Pradesh, and Orissa. At the same time, accompanying millet and weed species were examined in five plots (1 m²) in each of four typical cropping fields (sites) using the quadrat method. Voucher herbarium specimens and grain samples were collected along the survey route and deposited at Tokyo Gakugei University (Tokyo, Japan) and University of Agricultural Sciences (Bangalore, India). Information on agricultural practices, grain processing, food preparation, and vernacular plant names was gathered from local farmers.

The experimental strains (n = 78) were selected from these accessions and grown in the greenhouse at Tokyo Gakugei University to compare their morphological and ecological characteristics. In addition, three relative species of *S. pumila*: *S. italica* (n = 6, from Japan), *S. viridis* (n = 2, from Kazakhstan and Uzbekistan), and *S. verticillata* (n = 3, from India) were grown using the same methods.

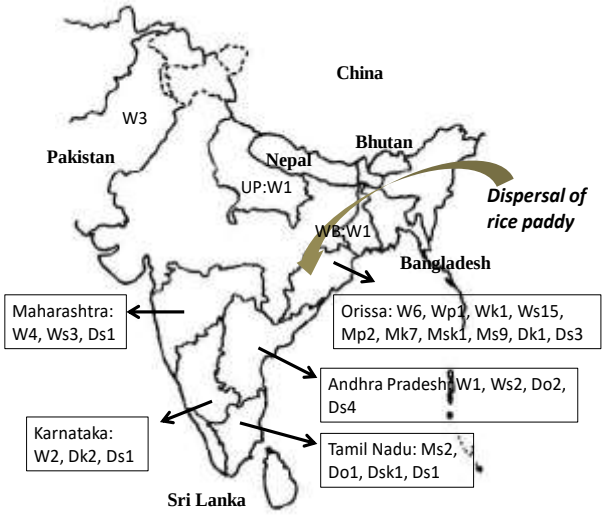


Figure 37. Sites from which *S. pumila* and the related species were collected in the Indian subcontinent.

Ten grains each of 60 strains were sown in a seeding box with row spacing of 8 cm and seed spacing of 2 cm on early June 6, 2002. Two weeks after sowing, germinated plants were transplanted into the greenhouse, with 30-cm row spacing and 15 cm between plants. Chemical fertilizer (N:P:K

= 8:8:5) was supplied at 100 g·m^{-2}. The following parameters of five types of *S. pumila* were measured at the each full-ripe stage: number of tillers, plant height, length and width of spike, length and width of flag leaf, last internode diameter, and duration to flowering. These types were three weed types; W, Wx, Mx associated with other grain crops, and two domesticated types; Dx mixed with *Paspalum scrobiculatum* and *Panicum sumatrense*. The lowercase character "x" indicates a main crop mimic of *S. pumila* as follows: "p" (paddy, *O. sativa* L.), "k" (*kodora*, *P. scrobiculatum*), "s" (*samai*, *P. sumatrense*), and "o" (others, e.g., *Elusine coracana*). These data were analyzed statistically using partial correlation coefficients and hierarchical cluster analysis (Ward method) by SPSS version 21 (IBM Corp).

Table 29. Materials used of *Setaria pumila*

Sample no. & Status	Main crop and remarks	Collection no.	Locality
1Ds-A	*Panicum sumatrense* mixed with *Eleusine coracana*	85-10-31-3-12	Duggamvapalli, Andhra Pradesh
2Ws-M	*P. sumatrense*	k87-9-28-9-4	Kumbharoshi (800m), Maharashtra
3Ws-M	*P. sumatrense*	k87-9-28-9-6	
4Ds-M	*P. sumatrense*	k87-10-1-7-8	16km from Lanja (200m), Maharashtra
5W-M	none	k87-10-3-3-1	Gabi (650m), Maharashutra
6Ws-M	*P. sumatrense*	k87-10-3-5-7	Nadagao village (541m), Maharashtra
7W-M	*Oryza sativa*	k87-10-4-6-7	8km W from Kolhapur (600m), Maharashtra
8W-M	*Setaria italica*	k87-10-5-10-5	Udtare village (652m), Maharashtra
9W-M	*S. italica*	k87-10-5-10-6	Udtare village (653m), Maharashtra
10Ms-O	*P. sumatrense*	k87-10-9-1-1	Sunabeda (895m), Orissa
11Ms-O	*P. sumatrense*	k87-10-9-1-6	
12Ms-O	*P. sumatrense*	k87-10-9-1-7	
13Ms-O	*P. sumatrense*	k87-10-9-1-8	
14Wsk-O	*P. sumatrense* mixed with *Paspalum scrobiculatum*	k87-10-9-2-2	Kundali village (875m), Orissa
15Ws-O	*P. sumatrense*	k87-10-9-5-6	Potang (895m), Orissa
16W-O	none	k87-10-10-2-1	7km from Sunabeda (900m), Orissa
17Ws-O	*P. sumatrense*	k87-10-10-5-5b	2km of Boiparigurha (608m), Orissa
18Ws-O	*P. sumatrense*	k87-10-10-5-6b	
19Ws-O	*P. sumatrense*	k87-10-10-5-10d	
20Ws-O	*P. sumatrense*	k87-10-10-5-13A	
21Ws-O	*P. sumatrense*	k87-10-10-5-13B	
22Ds-O	*P. sumatrense*	k87-10-10-5-14e	
23Ds-O	*P. sumatrense*	K87-10-10-5-16A	
24Ds-O	*P. sumatrense*	k87-10-10-5-16B	
25Ws-O	*P. sumatrense*	k87-10-10-6-8	Beragaon, 12km of Koraput (605m), Orissa
26Mk-O	*Pas. scrobiculatum*	k87-10-11-2-2	Anchalguda village, 20km of Kolaput (870m), Orissa
27Dk-O	*Pas. scrobiculatum*	k87-10-11-2-3	
28Mk-O	*Pas. scrobiculatum*	k87-10-11-2-5	
29Ws-O	*P. sumatrense*	k87-10-11-6-7	Damaniganda village (728m), Orissa
30Ms-O	*P. sumatrense*	k87-10-11-6-8	
31W-O	none	k87-10-12-2-3	Sagada village (240m), Orissa
32W-O	none	k87-10-12-2-7	
33Ws-O	*P. sumatrense*	k87-10-12-5-4	47km NW of Bhawanapatna (690m), Orissa
34Ws-O	*P. sumatrense*	k87-10-12-5-5	
35Ms-O	*P. sumatrense*	k87-10-12-5-7	
36Ws-O	*P. sumatrense*	k87-10-12-5-8	
37Wp-O	*Oryza sativa* mixed with *Pas. scrobiculatum*	k87-10-12-6-2	Balsora village (690m), Orissa
38Mp-O	*O. sativa* mixed with *Pas. scrobiculatum*	k87-10-12-6-3	
39Mp-O	*O. sativa* mixed with *Pas. scrobiculatum*	k87-10-12-6-4	
40Ws-O	*P. sumatrense*	k87-10-12-7-4	Duliguda village,11km of Gopalpur(922m), Orissa
41Ws-O	*P. sumatrense*	k87-10-12-7-5	
42Ws-O	*P. sumatrense*	k87-10-12-8-4	Dakuta (937m), Orissa
43Wk-O	*Pas. scrobiculatum*	k87-10-13-4-14	Puda Pali village (269m), Orissa
44Mk-O	*Pas. scrobiculatum*	k87-10-13-5-6	12km of Kharhiar (272m), Orissa
45Mk-O	*Pas. scrobiculatum*	k87-10-13-5-11	
46W-O	none	k87-10-14-2-1	Mandiapadar village (139m), Orissa
47W-O	none	k87-10-14-2-3	
48W-O	none	k87-10-14-2-4	
49Mk-O	*Pas. scrobiculatum*	k87-10-14-4-3	Budhitadar village (146m), Orissa
50Mk-O	*Pas. scrobiculatum*	k87-10-15-1-6	Ramisarda Tilemal (149m), Orissa
51Ms-O	*P. sumatrense*	k87-10-16-2-3	Kolarapaju village (766m), Orissa
52Ms-O	*P. sumatrense*	k87-10-16-2-4	
53Mk-O	*Pas. scrobiculatum*	k87-10-16-3-4	Bekarakhol village, 30km of Phulabani (522m), Orissa
54Ms-O	*P. sumatrense* mixed with *E. coracana*	k87-10-16-5-4	4km from Tikaball (569m), Orissa
55W-W	none	k87-11-7-0-26	Kalimpong, West Bengal
56Dk-K	*Domesticated type, a few mixed in Pas. scrobiculatum*	96-11-5-1a-2	Kalidevapura, Karnataka
57Ds-K	*A few mixed with P. sumatrense*	96-11-5-2b-6	Madhagiri, Karnataka
58Dk-K	*A little shattering, only one plant mixed with Pas.*	96-11-5-7-2	
59Ds-A	*P. sumatrense*	97-4-12-2-2	Jalaripalli, Andhara Pradesh
60Ds-A	*P. sumatrense*	97-4-12-2-3	
61W-U	weed mixed with *Echinochloa frumentasea*	96-11-17-0-1	Ranichauri, Uttar Pradesh
63Ws-A	*P. sumatrense*	01-10-8-1-5	Mulbagal, Andhra Pradesh
64Ws-A	*P. sumatrense*	01-10-8-2-5	Palmaner, Andhra Pradesh
66Ds-A	*P. sumatrense*	01-10-9-2-4	Dombarpally, Andhra Pradesh
69Ws-O	*P. sumatrense*	01-10-19-2a-3	Polehorebrdle, Orissa
70Ds-T	*P. sumatrense*	85-10-28-1-1	Morumu, Tamil Nadu
71Do-A	mixed stand	85-11-10-1-11	Gandrajupalli, Andhra Pradesh
72Do-A	mixed stand	85-11-10-1-16	
73W-A	mixed stand	85-11-10-1-18	
75W-P	*Vigna mungo*	85-9-15-5-2	39km from Abbottabad to Hazara, Pakistan
76W-P	mixed stand	89-9-29-3-3-5	47km from Muzafabad, Pakistan
762W-P	mixed stand	89-9-29-3-3-6	
77Dsk-T	*P. sumatrense* and *Pas. scrobiculatum*	89-10-25-3-7	Bawalia village, Mandia, Tamil Nadu
81W-K	*S. pumila* ssp. *pallide-fusca*, mixed stand	85-10-16-3-2	Namanahalli, Karnataka
82W-K	*S. pumila* ssp. *pallide-fusca*, mixed stand	85-10-17-3-3	Honnavara, Karnataka
84Do-T	mixed stand	85-10-27-3-6	Vellakadai (Goundar tribe), Tamil Nadu
85Ms-T	*P. sumatrense*	85-10-23-2-15	Kollimalai (Kotha tribe), Tamil Nadu
86Ms-T	*P. sumatrense*	85-10-23-2-7	

Sample number and status: W, weed type; M, mimic weedy medium type; D, domesticated type. Main crop: s, *samai* (*Panicum sumatrense*); k, *kodo* (*Paspalum scrobiculatum*); p, paddy (*Oryza sativa*); o, other species. Locality: A, Andhara Pradesh; K, Karnataka; M, Maharashtra; O, Orissa; P, Pakistan; T, Tamil Nadu; U, Uttar Pradesh; W, West Bengal.

Data analysis

The bands were detected on the gel at the finest level of sensitivity by Lane Analyzer (ATTO), the raw data were adjusted, and then the visible and reproducible bands were scored for accessions as present (1) or absence (0). The dendrogram of the AFLP markers was constructed using the neighbor-joining method and bootstrap analysis (PAUP* version 4.0) on all data matrices (Nei and Kumar 2000).

The results of AFLP on 72 accessions from the Indian subcontinent are shown in Table 3. Most bands showed polymorphic more than 81.7% to 94.1% polymorphisms, excluding the main bands were detected more than 70% of all accessions.

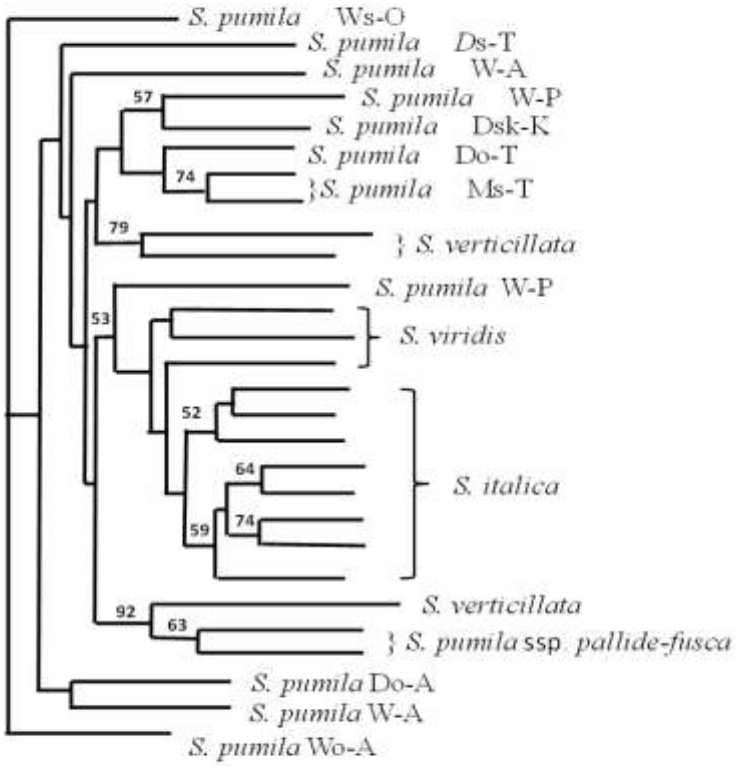


Figure 38. Dendrogram of neighbor-joining method based on AFLP markers of genus *Setaria*.

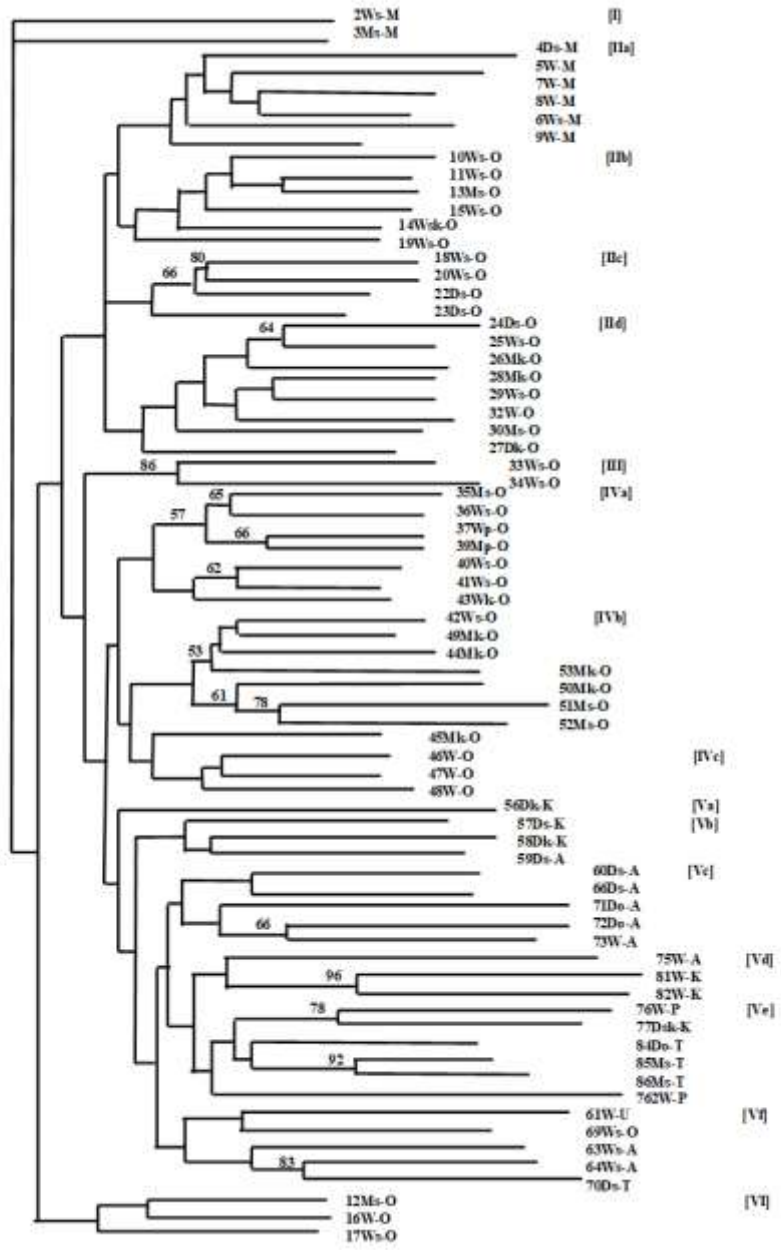


Figure 39. Dendrogram of neighbor-joining method based on AFLP markers of *S. pumila.*

The diversity of AFLP markers was compared among relative species (28 accessions) of *S. pumila* (14 including ssp. *pallide-fusca* 2), domesticated *S. italica* (8 from Japan), the ancestral weed *S. viridis* (3 from Central Asia), and the weed *S. verticillata* (3 from India). The dendrogram constructed with the neighboring-joint method is illustrated in Figure 38. The clusters of *S. pumila* were composed, successively, of Ws1 from Orissa; Wo1, Do1, and W1 from Andhra Pradesh; Ds1 from Tamil Nadu; and W1 from Andhra Pradesh. The other clusters included W1 from Pakistan, Dsk1 from Karnataka, and Do1 and Ms2 from Tamil Nadu. *S. pumila* ssp. *pallide-fusca* (2) from Karnataka and *S. verticillata* (1) from Andhra Pradesh formed a cluster. W1 of *S. pumila* from Pakistan was located as the neighbor of *S. viridis*. *S. verticillata* (2) was located in the cluster of *S. pumila*, but *S. viridis* (3) and *S. italica* (8) were located in the same cluster. The location of species

within clusters was not significant at $p \leq 0.05$ based on the bootstrap test, but the species were clearly categorized.

S. pumila (72 accessions) were divided into six clusters including 16 sub-clusters based on AFLP marker data as shown in Figure 39. Cluster I contained Ws1 and Ms1 from Maharashtra; Cluster III consisted of Ws2; and Cluster VI contained W1, Ws1, and Ms1 from Orissa. These clusters contained no domesticated type.

Cluster II (4 sub-clusters, 23 accessions) consisted of sub-cluster IIa (6), W4, Ws1, and Ds1 from Maharashtra; sub-cluster IIb (6), Ws (4), Ms1, and Wsk1 from Orissa; sub-cluster IIc (4), Ws2 and Ds2 from Orissa; and sub-cluster IId (8), W1, Ws2, Ms1, Ds1, Mk2, and Dk1 from Orissa. Cluster IV (three sub-clusters, 18 accessions from Orissa) consisted of sub-cluster IVa (7), Wp1, Mp1, Wk1, Ws3, and Ms1; sub-cluster IVb (7), Ws1, Ms2, and Mk4; sub-cluster IVc (4), W3, and Mk1. Cluster V (6 sub-clusters, 23 accessions) consisted of sub-cluster Va (1), Dk1 from Karnataka; Vb (3), Ds1, Dk1 from Karnataka, and Ds1 from Andhra Pradesh; Vc (5), W1, Do2 and Ds2 from Andhra Pradesh; Vd (3), W1 from Andhra Pradesh and W2 from Karnataka; Ve (6), W2 from Pakistan, Ms2, Dsk1, and Do1 from Tamil Nadu; Vf (5), W1 from Utter Pradesh, Ws1 from Orissa, Ws2 from Andhra Pradesh, and Ds1 from Tamil Nadu.

The domestication process for each species was a complex combination of natural and artificial selection, mimicry, hybridization, and polyploidy. Pioneer farmers required plants some to have some degree of tolerance to conditions (e.g., cold, hot, drought, harsh sunlight). Farmers continue to gather wild cereals in dry areas of Africa and the Indian subcontinent. For example, *Secale cereale* L. has acquired strong resistance to cold in high altitude or latitude areas, and farmers have been able to grow *S. cereale* mixed with wheat as a secondary crop as a companion weed under severe conditions (Vavilov 1926). Kobayashi (1987, 1989) proposed an integrated model of the domestication process of several millet species as secondary crops derived from weeds by mimicking companion weeds associated with *Oryza sativa* in the Indian subcontinent.

Increasing the size and shattering resistance in seeds are important factors in the domestication process. The partial correlation coefficients that describe control of seed size and shattering explain that the cylindrical spike has become longer, the last internode diameter of the main culm has thickened, and the flag leaf has widened for effective photosynthesis as a result of artificial selection by farmers.

The low coefficient between the number of tillers and the other characteristics reveals that the number of tillers in Dk has decreased during domestication by processes such as mimicry of *Pas. scrobiculatum*, while the number of tillers of Ds has increased as the mimicry of *P. sumatrense*. Separate selection processes functioned to both decrease and increase the number of tillers (Kimata unpublished). The low coefficients for length of flag leaf and ratio of length/width of the flag leaf to duration of flowering indicate that artificial selection has operated on the flag leaf, causing it to become narrower and to mature early under domestication.

The negative correlation between ratio of length/width of the flag leaf to plant height demonstrated that the flag leaf has become longer and narrower, while plant height has increased, as in Ds. The Ds of *S. pumila* matures early and has a relatively long and narrow flag leaf due to artificial selection, reflected in the significant negative correlations between length of flag leaf and the ratio of length/width of the flag leaf in relation to duration to flowering. In addition, Ds has

acquired a relatively long and narrow flag leaf as a result of taller plant height, as seen in the significant negative correlation between plant height and length/width of flag leaf.

During the evolutionary process from companion weed to secondary crop, which involved morphological mimicry of other species (Mo), *S. pumila* (Ds) became a slender-type mimic with long-narrow leaves as in *P. sumatrense*, while *S. pumila* (Do) became a thick-type mimic with wide leaves as in *Pas. scrobiculatum* and other species. Based on the Panton Formula Guide (Pantone Inc.), it was clear that the leaf, leaf sheath, culm, and glume of *S. pumila* exhibited mimetic coloration among species and demonstrated mimicry of coloration of *P. sumatrense* and *Pas. scrobiculatum*, according to anthocyanin composition revealed by HPLC analysis (Kimata 2015a).

From the cluster analysis, *S. pumila* cluster I clearly showed that the domestication process of *S. pumila* has occurred continuously in fields of *P. sumatrense* and other grain crops around the Deccan. Cluster II consisted of sub-cluster IIa; Ds1, Ms2, Mk4, Ws3 and W3 from Orissa, Dk2 from Karnataka, Ws2 from Maharashtra, and sub-cluster IIb; Ms1 and Ws1 from Orissa. Cluster II gives an example of the domestication process by mimicry, which *S. pumila* has become Dsk mixed with *P. sumatrense* and *Pas. scrobiculatum* in each fields. Cluster III revealed that the W type of *S. pumila* was distributed around the Indian Subcontinent as a cosmopolitan weed.

The domestication process of *S. pumila*, Dsk, has taken a route from weed type to companion weed and then to mimic companion weed with *O. sativa*, *P. sumatrense*, and *Pas. scrobiculatum* in Orissa. Therefore, the domestication process of *S. pumila* has moved forward as follows. First, the mimic companion weeds (Mks, mainly in Orissa) and second, the domesticated type (Do) evolved and moved south to the Deccan Plateau via Andhra Pradesh. After that, the domesticated type progressed from Dk to Ds in Karnataka and Tamil Nadu.

The natural intraspecific hybrids of *S. pumila* occurred continually in sympatric fields among weeds, companion weeds, mimic companion weeds, and domesticated types, as revealed by a geographic bias in both morphological characteristics and AFLP markers. There were two cases of mimicry, interspecific and intraspecific, in this domestication process. Interspecific mimicry was found in the mimic companion weed with *O. sativa*, *Pas. scrobiculatum*, and *P. sumatrense* and other species. The intraspecific mimicry occurred by continuous natural hybridization between weed and domesticated type and also though natural or artificial selection by farmers. The mimic companion weed type was quite similar to the domesticated type, but farmers were able to differentiate between the two by seed shattering.

The diversity of AFLP markers was compared among relative species of *S. pumila*, domesticated *S. italica*, the ancestral weed *S. viridis*, and another weed, *S. verticillata* (see dendrogram in Figure 38). Recently, Wang et al. (2009) and Zhao et al. (2013) indicated that the genome constitution of *S. verticillata* had diploid (BB) and tetraploid (AABB) forms based on GISH, while *S. glauca* (syn. *S. pumila*) was identified genome 'D,' but its genomic constitution was not known. Based on the dendrograms by Bayesian analyses for 5s rDNA and kn1 sequences, the A genome included *S. italica*, *S.* viridis, and *S. verticillata*; the B genome comprised *S. verticillata*, and the D genome consisted of *S. glauca* (syn. *S. pumila*). *S. pumila* (W-P) from Pakistan was located the neighbor of *S. viridis*. *S. pumila* ssp. *pallide-fusca* from Karnataka and *S. verticillata* from Andhra Pradesh made a cluster. The irregular positions in which *S. pumila* was located related to its multiple ploidy levels and obscure genomic constitution.

The AFLP methodology gave highly reproducible bands, and polymorphisms among individuals within accessions were very low (d'Ennequin et al. 2000). Small millet species including *S. pumila have* shown remarkable genetical variation (Lakshmi et al. 2002) because of its polyploidy and natural hybridization. The AFLP variation in *S. pumila* was generally high because of the grouping of many sub-clusters, but the bootstrap values were low in each sub-cluster. Intraspecific morphological differentiation was easily detected, but the variation in AFLP was reduced by natural hybridization. Therefore, based on the AFLP dendrogram, which was not directly influenced by the artificial selection by farmers, it was obvious that there was a regional bias; many accessions of mimic companion weed type were located in sub-cluster IVb, and the most accessions of the domesticated type were in Cluster V with little significance in bootstrap value. Moreover, Cluster IV, from Orissa only, did not include the domesticated type but contained the most accessions of mimic companion weed type. Cluster II from Maharashtra and Orissa indicated that the companion/mimic companion weeds coexist with the domesticated type mixed with other crops.

Domestication process of *Brachiaria ramosa*

B. ramosa is cultivated under pure single cropping as a sole tertiary crop, while *S. pumila* is still cultivated under mixed cropping with *P. sumatrense* as a minor domesticated plant. *B. ramosa* tolerates drought better than *S. pumila*, and has been undergoing a specializing adaptation to arid regions, and has nearly attained the tertiary domesticated phase. On the other hand, the landraces of *S. pumila* have adapted to drier fields in South India than in Orissa. *S. pumila* was almost always grown with *P. sumatrense*, but seemed to grow singly when the later fail to grow in severe droughts, as was observed in our survey of 1987. This possibly suggests that *S. pumila* could become an independent crop (Table 39 and Figure 40).

In this case of multiple polyploidy species, *S. pumila* indicated that diversity had been increased mainly by mimicry and inter- and intra-specific hybridization under natural and artificial selection. This domestication process has been promoted as a means of imparting adaptation to an arid climate, and also produced a symbiotic relationship among weeds, other crops, and farmers, while departing from an antagonistic one. The domestication process of *S. pumila* indicates the importance of weed-crop complexes and biocultural diversity as a plant-man symbiosis. The diversity of *S. pumila* and its relatives should be conserved both *in situ* and *ex situ*, especially in on-farm conservation sites.

Table 30. Cultivation and processing of *B. ramosa* and *S. pumila*

Method	Crop	
	Brachiaria ramosa	*Setaria pumila*
Cultivation		
plowing	three time by wooden spade	2~3 times by wooden spade
land grading	twice by wooden harrow	twice by wooden harrow
sowing time	middle August	late September~ealy August
sowing	broadcast	broadcast
croping system	single cropping	mixed cropping with *Panicum smatrense*
manuring	nil or organic fertilizer	organic fertilizer, 700~1000 kg/ha
weeding	nil or once by hands	nil
intertillage	nil or once	nil or once on 10~15 days after sowing
harvest time	end of Octover~early November	end of Octover~midle November
harvesting	ground level harvesting by sickle	ground level harvesting by sickle
Processing		
drying	more than three days~two weeks	eight~ten days
threshing	by stone roller	by cattle tapping
hulling	by stone huller or mechanical huller	by stone mortar and wooden pestle
polishing	by stone mortar	by stone mortar and wooden pestle
milling	by millstone	by millstone and wooden pestle

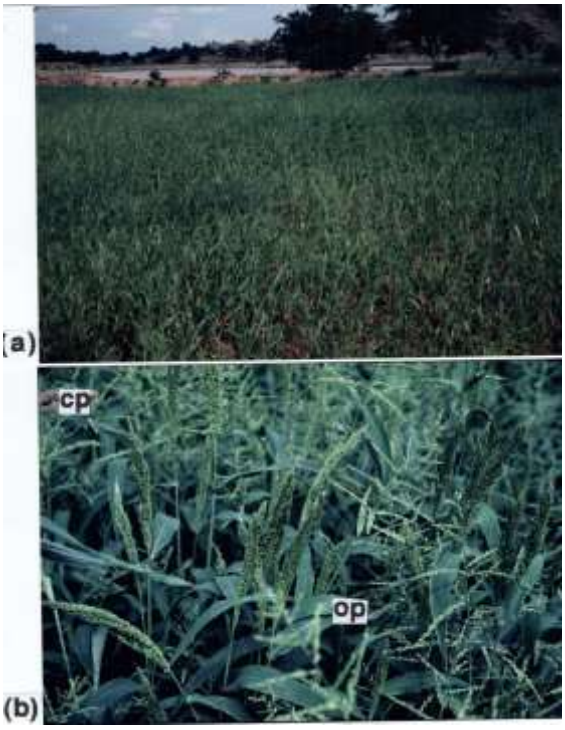


Figure 40. ***Brachiaria ramose***

a, a field at Tumkur, Karnataka; b, compact panicle of crop type (cp) and open panicle of mimic companion weed type (op).

Domestication process and linguistic differentiation of millets

Furthermore, this domestication process is supported by the linguistic recognition of their various vernacular names by farmers. For example, a mimic companion weed or semi-domesticated plant occurring with *Pas. scrobiculatum* was called *varagu korali*, meaning just the same as kodo millet, while a mimic companion weed or semi-domesticated plant occurring with *P. sumatrense* was

called *samuru korali*, meaning also just the same as little millet. The domesticated type was called various vernacular names (e.g., *korati, kora samuru, korin*) in each local language and region. The linguistic differentiation shows a close relationship to the domestication process (Chandra and Koppar 1990; Kawase 1987; Kimata et al. 2000, Kimata unpublished; Kobayashi 1987, 1989).

The vernacular names of millets were gathered through field surveys in the Indian subcontinent since 1983. Farmers have an appropriate awareness of the status of millets and their relative weeds in the domestication process. This symbiotic process between millets and farmers was reconstructed by integrating field observations, botanical experiments, archaeological data, and linguistic sources. There were various vernacular names in the Eastern Ghats and Southern Deccan Plateau, where Indian millets were widely cultivated with their relative species today. It is obvious that the several names in the old Indo-Aryan and Dravidian languages are related to the vernacular names of millets. *Brachiaria ramosa* and *Setaria pumila* have been domesticated from the weeds that grew around upland rice fields via a mimic companion weed type that was mainly related to *Panicum sumatrense* and other grain crops. *Brachiaria ramosa* has become an independent crop in pure stands, while *Setaria pumila* grows as a mixed crop with *Panicum sumatrense* and other millets. Consequently, *Brachiaria ramosa* and *Setaria pumila* are so-called "tertiary crops," meaning, they are a double secondary crop for the other millets and upland rice. The order of first occurrence of millets from historical sites generally supports this evolutionary process. This domestication center of millets covered the Eastern Ghats and Southern Deccan Plateau.

The indigenous millets of the Indian subcontinent have been domesticated across their ranges of present-day cultivation for some 3500 years (de Wet et al. 1983a; Fuller 2002; Pokharia 2008). These millets include *Paspalum scrobiculatum* L. (*kodo* millet), *Echinochloa frumentacea* Link (Indian barnyard millet), *Panicum sumatrense* Roth. (little millet), *Brachiaria ramosa* (L.) Stapf. (*korne*), *Setaria pumila* (Poir.) Roem. & Schult. (*korati*; syn. *Setaria glauca* (L.) P. Beauv.), *Digitaria cruciata* (Nees) A. Camus (*raishan*), and *Digitaria sanguinalis* (L.) Scop. (Chandra and Koppar 1990; de Wet et al. 1983a, b, c). The former three species seem to be secondary in origin, through the mimic and/or companion weeds of the rain-fed paddy and then upland rice in Eastern India. The next two species, *Brachiaria ramosa* and *Setaria pumila*, were domesticated as secondary crops that were associated with the other millets via their mimic companion weed types in South India (Kimata et al. 2000; Kimata 2015a, 2015b, Kobayashi 1987, 1989). *Digitaria cruciata* was domesticated in the late nineteenth century by Kashi natives in Meghalaya and is cultivated only in the Kashi Hills (Singh and Arara 1972). Unfortunately, *Digitaria sanguinalis* has disappeared, and its origin is not clear.

In contrast to other millets, which were probably domesticated in humid Eastern India, *Brachiaria ramosa* and *Setaria pumila* have adapted to the dry climate of the semi-arid tropics. *Brachiaria ramosa* was cultivated in the hot, arid red soil region of Southern India, whereas *Setaria pumila* was cultivated in the hot sub-humid ecoregion in red and lateritic soils of Orissa, as well as in the hot semi-arid ecoregion on red loamy soils of Southern India (Sehgal et al. 1992). *Brachiaria ramosa* tolerates drought better than *Setaria pumila*, it has undergone a specializing adaptation to arid regions, and it has nearly attained the tertiary domesticated phase (Kimata et al. 2000). On the other hand, the local varieties of *Setaria pumila* have adapted to drier fields in Southern India than in Orissa. *Setaria pumila* was normally grown with *Panicum sumatrense*, but it seemed to grow

singly when the latter failed to grow in severe droughts, which was observed in our 1987 survey. This possibly suggests that *Setaria pumila* could become an independent crop. *Brachiaria ramosa* is an underutilized millet that is restricted in cultivation today to dry areas in the two border districts of Tumkur and Anantapur in the states of Karnataka and Andhra Pradesh, respectively. *Brachiaria ramosa* is cultivated in pure stands as a sole tertiary crop, while *Setaria pumila* is still cultivated by mixed cropping with *Panicum sumatrense* and other grain crops as a minor domesticated plant. A tertiary crop is a type of double secondary crop of *Panicum sumatrense* and others and a secondary crop of upland rice.

The methodological concept of the "basic agricultural complex," the so-called "from seeds to stomach" idea, was proposed by Nakao (1967) while studying the origin of agriculture. A domesticated plant always is accompanied by a cultural complex, which includes cultivation practices, processing, cookery, religious use, vernacular names, and other aspects (Kimata and Sakamoto 1992). Bellwood and Renfrew (2002) recently proposed and examined their "farming/language dispersal hypothesis" cooperative across the disciplines of archaeology, linguistics, and genetics from a broad comparative perspective. These millets and their relative weeds also have many vernacular names in each locality and language. This report is concerned with the reconstruction of their domestication process, particularly *Brachiaria ramosa* and *Setaria pumila*, from the point of view of their vernacular names with reference to linguistic archaeology, because good linguistic data have not yet been sufficient for the indigenous millets (Fuller 2002; Southworth 2005).

Brachiaria ramosa was cultivated mainly in a few states of South India. This semi-arid area is subject to a savanna climate in Deccan Plateau. *Brachiaria ramosa* and its relatives are summer annuals and have many vernacular names in each locality and language as shown in Table 31. The following tables contain some vernacular names that are cited for the convenience of discussion, but the results of surveys are from the author's own data. This domesticated type has been known by various vernacular names in Maharashtra and South India (cf. Chandra and Koppar 1990; Kawase 1987; Kimata et al. 2000; Kobayashi 1987, 1989). The domesticated type was called similar names: *hama pothaval* in Maharashtra, *chama pothaval* in Kelara, and *kama pampul* and *palapul* in Tamil Nadu. On the other hand, it was called different names in the border area between Andhra Pradesh and Karnataka, mainly *korne*, *korneki*, and *andakora*, and sometimes *pedda sama* and *disakalu*. The mimic companion weed type was known as *koothi same*, *sakalati same*, and *pil same* in Tamil Nadu. The weed type was known as *gusara pata* and *chusara mata* in Orissa, and *akki hullu* and *votlu kosavu* in Andhra Pradesh.

Table 31. Vernacular names of *Brachiaria ramosa*

State	Language	Status	Vernacular names
Orissa	Oriya	Weed with *Pas. scrobiculatum*	gusara pata, chusara mata
		Weed/Domesticated?	ghusara pata, lota, ghada langi
Maharashtra	Marathi	Domesticated	chama pothaval [3]
Andhra Pradesh	Telugu	Weed	akki hullu, votlu kosavu
		Domesticated	andakora, anda korra, *pedda sama* [1], disakalu, edurigaddi
Karnataka	Kannada	Domesticated	kornne, korale, korne, korneki, kornike, bennakki hullu [3]
Tamil Nadu	Tamil	Mimic companion weed with *P. sumatrense*	koothi same, sakkalati same, *same melatti* [5], pil sama, pani varagu
		Domesticated	kam pampul, palapul [3]
Kelara	Malayalam	Domesticated	chama pothaval [3]

Italics cited from 1) Fuller 2002, 2) Kobayashi 1991, 3) Ambasta 1986.

Setaria pumila was cultivated at a few hill sites that were mainly in Orissa and South India. This semi-arid area is also subject to a savanna climate in Deccan Plateau. *Setaria pumila* and its relatives are summer annuals and have many vernacular names in each locality and language as shown in Table 32. The domesticated type was known by a great variety of vernacular names in Orissa and in the border area between Andhra Pradesh and Karnataka (cf. Chandra and Koppar 1990; Kawase 1987; Kimata et al. 2000; Kobayashi 1987, 1989). These names were usually shortened to a single word, such as *nehari* in Orissa, *lingudi* in Maharashtra, *korati* in Andhra Pradesh, *korlu* in Tamil Nadu, and *korin* in Karnataka, and the names were sometimes composed of two words, including *kuku lange* and *kukur lange* in Orissa, *kora samuru* in Andhra Pradesh, and *samuru korra* in Karnataka. The mimic companion weed type was known by many vernacular names, too. Further, these names were usually a single word, such as *nauri* in Bihar, *lingri* in Orissa, *nauri* in Madhya Pradesh, *korale* in Andhra Pradesh, and *erikorra* in Karnataka. They sometimes have adjectives that indicate the associated plants, for example, in Andhra Pradesh, *varagu korali* and *varagu sakkalathi* indicate a companion weed of *kodo* millet, while *samalu korali* and *arasama* indicate a companion weed of little millet. The weed type was often called *navari* in Madhya Pradesh, *ghas* in Orissa, and unique names such as *ghoda langi*, meaning horse tail, in Orissa and *sana korulu*, meaning little foxtail millet.

Table 32. Vernacular names of *Setaria pumila*

State	Language	Status	Vernacular names
Bihar	Hindi	Mimic companion weed with *Pas. scrobiculatum*	nauri, navri, nebri, neuri, nevri, nibri, harri, tutuam
Orissa	Oriya	Weed	ghoda langi, kukulange, birailange and gaso(Kondha), ghas; *bilai lange* and *lota* [2]
		Mimic companion weed with *E. coracana, Pas. scrobiculatum, P. sumatrense* and *Oryza sativa*	lingri, ghas lingudi, kukuru lange; *ghas lingri* [2]
		Domesticated type with *Pas. scrobiculatum* and *P. sumatrense*	nehari, kuku lange, kukur lange (Konda Dora), kukuru range; *kukuru lange* [5], kuku lange, lingudi, lengudi, kukukangdi
Madhya Pradesh		Weed	navari, navri, naviri (Variga)
		Mimic companion weed with Pas. scrobiculatum	*harri, nauri, navri, neuri, nibri, tutuam, nebri* and *nevri* [2]
Maharashtra	Marathi	Weed	ghas lingudi
		Domesticated type	lingudi, lengudi
Andhra Pradesh	Telugu	Weed	sana korulu
		Mimic companion weed with *Pas. scrobiculatum* and *P. sumatrense*	korale, kurale, kurule kaddi, korinlu, samuru korali, arasama, varagu korali, varagu sakkalathi
		Domesticated type	korati, korindlu, korinlu, koral, kora samuru, same korulu, samelu, sama, arasama, chinna sama, tela samuru, nerige, nerigalu, *samuru korra* [2]
Tamil Nadu	Tamil	Domesticated type	korlu, korati
Karnataka	Kannada	Mimic companion weed with *E. coracana, Pas. scrobiculatum, P. sumatrense* and *Oryza sativa*	erikorra, korindulu, arasama, nerigalu, neriya
		Domesticated type with *P. sumatrense*	korin, korra, korrulu, samuru korra
Others	Hindi	Domesticated type	*bandhra* [1]

Italics cited from 1) Fuller 2002, 2) Kobayashi 1991.
Austin 2006: *korai* [*kora, korali*] (Bengali, Deccan, Hindi, India and Bangladesh), *bandra* (Hindi, India), *varagu korali* (*varagu*, firewood, *korali*, ear or corn, Tamil)

The vernacular names of other indigenous millets and rice in the Indian subcontinent are shown in Table 33. The domesticated type of *Panicum sumatrense*, a summer annual, was usually called *samai*, *same*, *sama*, and similar names in South India, while it was called *vari* and *wari* in Maharashtra, *gurji* and *koeri* in Orissa, and *gondula* in West Bengal. Further, indigenous people called it various names, including *kutki* (Vaiga) and *mejheri* (Gobdi) in Madhya Pradesh; *gundli* (Munda) in Bihar; *ghantia* (Kunda Tading), *gurgi* (Kunda Dora), and *suau* (Paraja) in Orissa; and *batta* (Kotha) in Tamil Nadu. The mimic companion weed type was identified and called *akki marri hullu*, meaning weed-like rice, *kadu same*, meaning weed little millet, and *kosu samalu* only in Karnataka, while the weed type was sometimes called *kadu* and *fodo* in Karnataka, *gabat* in Maharashtra, and *erigola* and *arasama* in Andhra Pradesh.

Table 33. Vernacular names of other indigenous millets and rice

Country / State / Growth habit	Language	Status	Vernacular names (Indigenous people) *Paniocum sumatrense* summer annual	*Paspalum scrobiculatum* perennial	*Echinochloa frumentacea* summer annual	*Digitaria ouruoista* summer annual	*Coix lacryma-jobi* perennial	*Oryza sativa* perennial
Pakistan								
NWFP								chawl
Gilgit								
Baltistan								
Punjab					*sarou* [4], *swank* and *sawank* [6]			
Baluchistan					*sawara* [6]			
India								
Jammu & Kashimir		domest			*karin* [4]			
Himachal Pradesh		domest		katai				
Uttar Pradesh	Hindi	domest		koda				dhan
(Uttaranchal)		domest			jhangora, jangora, madira			dhan
Punjab		domest	*kutki* [4]	*kodora* [4]				
Haryana								
Rajasthan								
Gujarat		domest		*menya* [4]				
Madhya Pradesh		weed			chichvi = *E. colona*		gulru = *C. gigantia*	pasahi =*O. rufipogon*
		comp. weed		kodo, *kodaira, kodaila and marendo* [2]	chichvi, *nauri* [2]			
		domest	kutki (Vaiga), mejheri (Gondi, Kal and Vaiga)	kodo	sawan, savan, sawai			dhan, chawal, lehi = upland rice
Maharashtra	Marathi	wild		kotcha				deobath =*O. rufipogon*
		weed	gabat		sankari wari			
		domest	vari, wari, nagri, sama, varag, kodra, warai [2]	kodo, kodora, harik	wari			tandul
Bihar (Jharkhand)	Hindi	wild		khar sami = *Pas. indicum, kodo wani; matwani* and *kharasami (Pas. sp.)* [2]	sain		gurya	
		comp. weed		kodo war, *marendo* [2]				
		domest	gundli (Munda)	kodo (Munda)	sawan, swan, sama			chawal, dhan, gora-dhan = upland rice
Orissa (Chattisgarh)	Oriya	weed		kodo-ghas, goddo	dhela = *E. colona*		korankhar = *C. gigantia*, gorigodio	balunga
		comp. weed		*kodoghas* (Paraja), *mandia* and *kodo* [2]				
		domest	gurji, koeri, suan	kodo, koddo, koda	jhari, dhatela			dhan, gadeba dhan = upland rice
	Others	domest	ghantia (Kunda Tading),gurgi (Kunda Dora), suau (Paraja), nalisuan, kusuda, kosula (Others)		gruji suau (Paraja)			
Andhra Pradesh	Telugu	weed	ara sama, erigola					
		domest	same, sama, samuru, *nella shama* [4]	arika, *allu* [4]	ooda, oodalli, *bouth-shama* [4]			paddy, biyyam
Tamil Nadu	Tamil	domest	sawa, sama, samuru, samai, *cha'mai* and *shama* [6], batta (Kotha)	varagu, *waragu* [2], *kodra* and *harik* [2]	kudurai-vali, korali		kassaibija [4]	paddy
Karnataka	Kannada	weed	kadu, fodo					
		comp. weed	akki marri hullu, *akki hullu, kavadadara hullu, kaddu same, kosu samalu* and *yerri arasamulu* [2]					
		domest	same, sawan, sami, hejjanve, *pani varagu* and *samulu* [2]	varagu, arka, alka, kodo	wadalu			gouri
Kerala								
West Bengal	Bengali	weed/ domest			*shama = E. colona* [4]		garemara = *C. gigantia*	
		domest	*gondula* [4]	*koda* [4]	*sama* and *kheri* [4]		*gurgru* and *kunch* [4]	
Megaraya	Khasi	domest				raishan		
Nagaland		domest					*re-si"* [4]	chahau
Others	Hindi	domest	*shavan* [1], *kutki* and *gundli* [4]	*kodu* and *kodhra* [1], *kodaka* [4]	*sa'nwa, sa'muka* and *sawa* [4], *shama, sanwa* and *sawank* [1]		*gurlu, giral* and *garahedua* [1], *kauch-gurgur, saukru'* and *lechusa* [4]	*vrihi* [1]
	Sanskrit	domest		*kora'susha* and *kodrava* [4]				
	NW Province	domest		*kodon* and *marsi* [4]	*sarwak* and *shamak = E. colonum* [4]			
	Deccan	domest			*kathli* [4]			
	unknown	domest						
Nepal	Nepalese	weed			sama and ketu (Newar) = *E. oryzicola*			
		domest		kodra				dhan, paddy
Bhutan	Bhutanese							
Bangradesh		domest						
Sri Lanka	Sinhalese	domest	*mene'ri* [4]	*wal-amu* [4]	*wel-marukku* [4]		*ki'kir-rindi"* [4]	

Italics cited from 1) Fuller 2002, 2) Kobayashi 1991, 4)Church 1886, 6) Kawase 1991, ..

The domesticated type of *Paspalum scrobiculatum*, a perennial, was mainly called *kodo*, *kodora*, and similar names, but it had different names such as *harik* in Maharashtra; *arik* in Andhra Pradesh; *arka*, *alka*, and *varagu* in Karnataka; and *varagu* in Tamil Nadu. The mimic companion weed grew in upland rice fields. It was called *kodo* and *kodaira* in Madhya Pradesh, *kodo war* in Bihar, and *kodoghas* (Paraja) in Orissa. The wild/weed type was called *kotocha* in Maharashtra, *khar sami* and *kodo wani* in Bihar, and *kodo ghas* in Orissa.

The domesticated type of *Echinochloa frumentacea*, a summer annual, was known as *jangora* in Uttar Pradesh; *sawan* and similar names in Madhya Pradesh and Bihar; *sankari wari* in Maharashtra; *jhari*, *dhatela*, and *gruji suau* (Paraja) in Orissa; *ooda* in Andhra Pradesh; *kudurai vali* in Tamil

Nadu; and *wadalu* in Karnataka. The ancestral weed species, *Echinochloa colona* was called *chichivi* in Maharashtra, *dhela* in Orissa, and probably *sain* in Bihar. *Digitaria cruciata* was a summer annual called *raishan* only in Kashi Hills. The domesticated type of *Coix lacryma-jobi* was a perennial called *re-si* in Nagaland (Church 1886), while the other weed species that often invaded rice paddy fields was called *gulru* in Madhya Pradesh, *gurya*, meaning small, in Bihar, *korankhar* in Orissa, and *garemara* in West Bengal.

Oryza sativa L., a perennial, was usually called *chawal* or *dhan*, but the upland rice was called *lehi* in Madhya Pradesh, *gora dhan* in Bihar, *gadeba dhan* in Orissa, and probably *gouri* in Karnataka. The wild relative *O. rufipogon* Griff. was used specially for a festival food and called *pasahi* in Madhya Pradesh, *deobath* in Maharashtra and probably *balunga* in Orissa.

The vernacular names of Asian and African millets in the Indian subcontinent are shown for comparison with those of Indian millets in Table 34. These species are all summer annuals. *Panicum miliaceum* L. was widely called *cheena* and similar names, while it was known as *wari* and *tane* in Maharashtra and *varagu* and similar names in Orissa, Andhra Pradesh, Tamil Nadu, and Karnataka. *Setaria italica* (L.) P. Beauv. was also widely called *kangani*, *kauni*, and similar names in Sanskrit, while it was called *rala* and *rai* in Maharashtra, *korra* and *navane* in Andhra Pradesh, *korra* and *thenai* in Tamil Nadu, and *navane* in Karnataka. *Eleusine coracana* Gaertn. was usually called *ragi* in Madhya Pradesh, Orissa, and South India, while it was called *mandua*, *marwa*, and similar names in Uttar Pradesh and Bihar, *natuni* and similar names in Maharashtra and Karnataka, *tamada* in Andhra Pradesh, *kapai* in Tamil Nadu, and *kodo* and similar names in Uttar Pradesh, West Bengal, and Nepal. Further, indigenous people called it various names, such as *manje suau* (Paraja), *mandia* (Kondho), and *pahado mandia* (Kond Dora) in Orissa. *Sorghum bicolor* Moench was generally called *jowar* and similar names, but it was called *cholam* in Tamil Nadu, *junero* in West Bengal, and *junero makai* in Nepal. *Pennisetum glaucum* (L.) R. Br. was also generally called *bajra* and similar names, but it was sometimes called *kayna* in Orissa, *sajja* in Andhra Pradesh, and *cumba* and similar names in Tamil Nadu.

Table 34. Vernacular names of Asian and African millets in Indian subcontinent

Country / State / Growth habit	Language	Status	Vernacular names (Indigenous people) *Panicum miliaceum* summer annual	*Setaria italica* summer annual	*Eleusine coracana* summer annual	*Sorghum bicolor* summer aannual	*Pennisetum glaucum* summer annual
Pakistan							
NWFP			*olean* [6]	*ghgh, ghok, gokhton, gokhtan, grashik, grach, gras* and *grass* [6]			bajera, baijera
Gilgit			*olean, chiena, cheena, bau* and *onu* [6]	*gras, cha, cheng* and *cheena* [6]			
Baltistan			*tzetze* [6]	*cha* [6]			
Punjab				*kangani, kangni* and *kongoni* [6]	*mandoh* [6]	jowar, *jowari* [6]	bajra,
Baluchistan							
India							
Jammu & Kashimir	Kashimiri						
Himachal Pradesh			charai	kauni			
Uttar Pradesh	Hindi	weed			*khadua* = hybrid by *E. indica* [2]		
		comp. weed			*jhhadua* = hybrid by Indaf [2]		
		domest	china, sawan	kangani, kangooni	mandua, ragi	jowar, jwar, juara	bajra
(Uttaranchal)		domest	cheena, chin	kauni, kouni, korin, konin	mandua, manduwa, marwa, koda		
Panjab	Panjabi						
Haryana							
Rajasthan							
Gujarat	Gujarati						
Madhya Pradesh		wild/weed					
		domest		kang, kakun	ragi, madia	jowar	bajira
Maharashtra	Marathi	wild/weed			nachuni = *E. indica*		
		domest	wari, tane	rala, rai	nachani, nachuni, nachana, ragi	jowar, jowari, jowary	bajeri, bajri
Bihar (Jharkhand)	Hindi, Bihari	weed			*marwani, malwa* =*E. indica* [2]		
		domest	cheena	kauni	marua, maruwa, *malwa*	jowar	bajera
Orissa (Chattisgarh)	Orya	wild/weed			jangali-suau (Paraja) = *E. indica*		
		domest	pani-varagu, cheena	kangu, gangu	ragi, manje-suau (Paraja), mandia (Kondho), pahado-mandia (Kond Dora)	jonna, jhna, jowary, jowar	kayna
	Others	domest		kangul (Paraja)			
Andhra Pradesh	Telgu	domest	variga	korra, kora, koralu, navane	ragi, tamada	jonna, jower	bajera, sajja, *gantilu'* [4]
Tamil Nadu	Tamil	domest	pani varagu, *varagu* and *katacuny* [4]	thenai, korra, *thennai* [1], *tinai* [4]	ragi, kapai	jowar, jara, jora, cholam	bajera, cumba, cumbu, *cumbu'* [4], *kambu* [6]
Karnataka	Kannada	weed			*kadu ragi, ragi kaddi,* = *E. indica* [2]; *hullu* = hybrid by Indaf [2]		
		domest	baragu	navane, nawane	ragi, nachina	jowar	bajra
Kerala							
West Bengal	Bengali	domest	*cheena* [5]	*ka'kun* [4]	kodo	jowar, junero	
Others	Hindi	domest	*chin, morha* and *anu* [1], *chena* and *chi'na* [4], *cheena* [5]	*kangni, kangu* and *kakun* [1], *ka'ngni, ta'ngan, kayuni* and *rawla* [4]	*ragi* [4]		*ba'jra, ba'jri* and *lahra* [4]
	Sanskrit	domest	*vrihibheda* [4], *u^nu^* and *vreelib-heda* [5]	*ka'ngu* and *priyangu* [4], *kungu^* and *priyungu^* [5]			
	unknown	domest	*sa'wan-jethwa, kuri, phikar, ra'li* and *bausi* [4], *worga* (Telinga) [5]			*joa'r* [4]	
Nepal	Nepalese	domest	china	kauni, kaoni-tangure	kodo	junero-makai	bajra
Bhutan	Bhutanese						
Bangradesh				kaaun			
Sri Lanka	Sinhalese			*tana-ha'l* [4]			

Italics cited from 1) Fuller 2002, 2) Kobayashi 1991, 4) Church 1886, 5) de Candole 1989, 6) Kawase 1991.

The vernacular names of the other cereals are shown in Table 35. *Triticum aestivum* L. was called *gehun*, *godi*, and similar names. *Triticum dicoccum* Schübler, Char. et Descr. was *gangil* in Tamil Nadu and *aja* in Karnataka. *Hordeum vulgare* L. was called *jao* and similar names. Those two species are winter annuals. *Avena sativa* L. was not cultivated in South India. *Zea mays* L., a summer annual, was widely called *makai* and similar names, while the relative teosinte was introduced for fodder and was called *jenera* in Bihar.

Table 35. Vernacular names of other cereals in Indian subcontinent

Country	Language	Status	Vernacular names (Indigenous people)			
State			*Triticum aestivum*	*Hordeum vulgare*	*Avena sp.*	*Zea mays*
Growth habit			winter annual	winter annual	winter annual	summer annual
Pakistan			ghandam, suji			makai
India						
Jammu & Kashimir						
Himachal Pradesh						makka
Uttar Pradesh	Hindi	domest				makai, makka, maki
(Uttaranchal)		domest	gehun			makka
Punjab						
Haryana						
Rajasthan						
Gujarat						
Madhya Pradesh		wild/weed				
		domest	gahun	jao		makai
Maharashtra	Marathi	wild/weed				
		domest				makka
Bihar (Jharkhand)	Hindi	domest				makai, jenera = teosint
Orissa (Chattisgarh)	Orya	wild/weed				
		domest	ghaun, gahomo			makka
Andhra Pradesh	Telgu	domest				
Tamil Nadu	Tamil	domest	godi, gangil = *T. diccocum; godome, kothimai and kothi* [4]	gangi		
Karnataka	Kannada	domest	aja = *T. diccocum*			makai
Kerala						
West Bengal	Bengali	domest				
Megaraya						
Nagaland						
Others	Hindi	domest				
	unknown	domest				
Nepal	Nepalese	domest	gaun, tro	jau, ne, uwa (Sherpa)		makai
Bhutan	Bhutanese					
Bangradesh						
Sri Lanka	Sinhalese					

The wild types, which were ancestral species of Indian millets, grew in wet places or habitats such as around pond peripheries and river sides. They also invaded rice paddy fields. In Pakistan, Nepal and India, many grass species, Poaceae, grow in paddy fields and on levees. Eventually, these weeds grew together in rice paddy and/or upland fields as a sympatric habitat and then became companion weeds. Some companion weeds mimicked the morphological and ecological traits of rice and became mimic companion weeds. The relationship between these plants and farmers

gradually changed from subconscious and antagonistic to friendly. Farmers began to use them for fodder and insurance crops under a semi-domesticated status through the symbiotic situation. Finally, these plants were independently cultivated for food grains under a domesticated status. Therefore, this evolutionary process established a symbiotic relationship among plants and farmers (Kimata 2015a, 2015b). There are two types of mimicry in this process. One type is inter-specific to different species under the status of companion weed type, while the other is intra-specific to the same species as a result of hybridization between the domesticated type and the closely related weed type.

The domestication process is supported by the linguistic recognition of various types by farmers, such as the weed, companion weed, mimic companion weed, semi-domesticated, and domesticated types of *Brachiaria ramosa* and *Setaria pumila*, in their vernacular names (Tables 31 and 32). The linguistic differentiation shows a close relationship to the domestication process, for instance, in Jalaripalli Village, Andhra Pradesh, where *Setaria pumila* that is mixed with little millet is called *kora samuru*, meaning foxtail millet-like little millet, and *tela samuru*, meaning the grains mixed with little millet, which is sold at a local market. This linguistic recognition suggests clearly the agro-ecological status of *Setaria pumila* as a secondary origin (Kimata et al. 2000).

The vernacular names of *Panicum sumatrense* and *Paspalum scrobiculatum* distinguish three types in their domestication process. The names of the mimic companion weed type are called, for example, *akki hullu* (little millet), meaning a rice-like weed, and *kodoghas*, meaning a kodo millet-like weed in upland rice fields (Kobayashi 1991). The linguistic differentiation indicates that both species were also a secondary crop via a mimic companion weed in upland rice fields. This thoroughly conforms to the observations that were made in the fields. The vernacular name of *Echinochloa frumentacea* is clearly distinguished from that of *Echinochloa colona*, which is one of the ancestral species (Yabuno 1962). For instance, the former is called *jhari* and the latter is *dhela* in Orissa (Table 35). Sometimes, the same names were used by farmers to name *Panicum sumatrense* and *Echinochloa frumentacea*, *same* and *sawan*, but the names were not used in the same place and time. In the same way, the vernacular name of *Eleusine coracana* is distinguished from a relative weed, *Eleusine indica*, and the hybrids. However, the weeds associated with other millets and cereals have no names (Tables 36 and 37). Interestingly, *Panicum miliaceum* and *Setaria italica* have various names in North-West Frontier Province and Gilgit, Pakistan (Kawase 1991). The vernacular names of Indian cookery-used millets are unique, particularly in South India, because rice (eastward) and wheat (westward) are staple foods today in the other states (Kimata 1991).

The linguistic archaeological names of millets and other cereals are summarized in Table 35. The old Indo-Aryan names for *Brachiaria ramosa*, *Setaria verticillata*, *Setaria pumila*, and *Panicum sumatrense* are not found in the ancient literature (cf. Southworth 2005). This might indicate that these millets were domesticated in India relatively recently. In contrast, because *Paspalum scrobiculatum* is named *kodorava*, this word is considered to be the origin of *kodo* and *kodora*. The word *syamaka* for *Echinochloa frumentacea* is considered a derivation of *shama* and *sama*. The word *cina(ka)* of *Panicum miliaceum* is also considered to be the origin of *cheena*, and the words *kanku(ni)* and *rahala* for *Setaria italica* are the origin of *kangani*, which was widely used, and *rala*, which was used in Maharashtra. The word *madaka* for *Eleusine coracana* is considered to be the origin of *mandua* in Uttar Pradesh and the word **bajjara* is the origin of *bajra* (*, reconstructed

forms by Southworth 2005). The Dravidian name **var-ak-* for *Paspalum scrobiculatum* and *Panicum miliaceum* is considered to be the origin of *varagu*, and the names **tinai* and **nuv-an-ay* for *Setaria italica* are the origin of *thenai* in Tamil Nadu and *navane* in Andhra Pradesh and Karnataka. Because these species have old Indo-Aryan or Dravidian names, they might have been introduced from the Western areas or domesticated within India a relatively long time ago, according to the archaeological evidence (Weber 1992).

Table 35. Summary on linguistic archaeological names of millets and other cereals

Species name	English name	Old Indo-Aryan	Dravidian	Others
Brachiaria ramosa	browntop millet	?	see Table 1	
Setaria verticillata	bristly foxtail	?	?	
Setaria pumila	yellow foxtail	?	see Table 2	
Panicum sumatrense	little millet	?	see Table 3	
Paspalum scrobiculatum	kodo millet	*kodrava*	**ar-V-k-, *var-ak-*	**var-ak-* (Tamil, Malayalam, Kannada), **ar-Vk-*(Kannada, Telugu)
Echinochloa frumentacea	Sawa millet	*syamaka*	see Table 3	
Digitaria cruciata	Khasi millet	nil	nil	see Table 3
Coix lacryma-jobi	Job's tear	nil	?	
Oryza sativa	rice	*vrihi*	**var-inc*	see Table 3
Oryza rufipogon	wild rice	*nivara*	*navarai/nivari*	see Table 3
Panicum miliaceum	common millet	*cina(ka)*	**var-ak-*	**ə-rig* (Proto-Munda), **var-ak-* (Telugu)
Setaria italica	foxtail millet	*kanku(ni), *kangu(ni), tanguni, (rahala)*	**kot-, *tinai, *tin-ay, *nuv-an-ay*	**kam-pu* (Tamil, Malayalam), **ar-Vk-* (Kannada, Gondi/Gorum, Kuwi),
Eleusine coracana	finger millet	*madaka*	**arak/*arak-*	*deray* (Kherwarian Munda),
Sorghum bicolor	sorghum	*yavanala, yavakara*	**conn-al*	**gang(-)gay* (Proto-Munda)
Pennisetum glaucum	pearl millet	**bajjara*	**kampu*	**kam-pu* (Kannada, Telugu)
Triticum aestivum	wheat	*godhuma*	**kul-i*	*godi* (Kannada),
Hordeum vulgare	barley	*yava*	**koc-/*kac-*	*kaj* (Kota/Konkani), *koj* (Toda), *gajja* (Prakrit)
Avena sativa	oat	?	?	see Table 5
Zea mays	maize	nil	nil	see Table 5

Modified and based on F.C. Southworth (2005)
Reconstructed forms are conventionally preceded by astarisks to denote non-attestation (Southworth 2005)

The first occurrence of grain crops in South Asia is summarized in Table 8, which is based on Fuller et al. (2001) but modified with additional information (Fuller and Madella 2001; Fuller, personal communication). *H. vulgare*, *Triticum* species (great many), and *Avena sativa* (a few) were identified in the Early Phase (around 4500 B.C.) of Harappan sites. *O. sativa* (many) and *Panicum miliaceum* (a few) were identified in the Mature Phase (around 2600 B.C.). Then, *Setaria* species (great many), *Sorghum bicolor* (many), and *Pennisetum glaucum* (syn. a*mericanum*, trace) were found in the Late Phase (around 2000 B.C.). The following species were found in early South Indian sites (2300 to 1800 B.C.): *Panicum sumatrense* (trace), *Brachiaria ramosa* (many), *Setaria verticillata* (many), and *Setaria pumila* (trace). Then, traces of *Paspalum scrobiculatum* and many *Echinochloa* cf *colona* (possibly *Echinochloa frumentacea*) were identified in the late sites (1800 to

1200 B.C.). Asian millets occurred historically in the following order: *Panicum miliaceum*; *Setaria* species; then *Brachiaria ramosa*, *Setaria verticillata*, *Panicum sumatrense*, and *Setaria pumila*; and *Echinochloa* cf *colona* and *Paspalum scrobiculatum*. However, *Brachiaria ramosa*, *Setaria verticillata*, *Setaria pumila*, and *Echinochloa* cf *colona* might have been gathered as a wild grain.

The naming scheme of millets and their relative weeds is summarized in Table 36. Farmers have four stages of awareness of the symbiotic process between them and plants. They are unknown (stage I), non-distinctive (II), identified (III), and classified into some local varieties (IV). In stage I, the farmers have no name for wild/weed plants and call them *ghas* and *hullu*. In stage II, the farmers use the same name for the crop (*ragi*) and weed (*ragi*). In stage III, the farmers identified and called millets a specific name, for instance, *madua* for *Eleusine coracana* (domesticated) and *khadua* for *Eleusine indica* (weed). Furthermore, farmers added a few adjective words to the root of the millet name, for example, to mean "weed" (*ghas lingudi*, meaning weed of *Setaria pumila*) and "like another crop" (*same melatti*, meaning mimic weed like little millet), and to indicate a morphological (*bilai lange*, meaning cat's tail) or ecological trait (*yerri arasamulu*, meaning weed with grain shattering) and a utility (*pil sama*, meaning *Brachiaria ramosa* for fodder). In stage IV, farmers classified the millets into some local varieties, for example, *Eleusine coracana* was known as *marua* and was classified into the varieties *agat-* (early), *madhyam-* (medium), and *pichhat-* (late); and a weed, *Eleusine indica*, was known as *maruani*. As a consequence of this survey, farmers appear to have an appropriate awareness of the status of millets and their relatives, even though they sometimes use the same names for millets in different places.

Table 36. Naming scheme of millets and weeds by farmers

Stage	Awareness	Typical cases (species name) [meaning]
I	**Unknown**	no name: ghas, hullu [weed]
II	**Non distinctive**	the same name of crop as weed: ragi, malwa (*Eleusine coracana*)/ragi, malwa (a weed, *E. indica*) kodo (*Paspalum scrobiculatum*) /kodo (the weed) kukuru lange (*Setaria pumila*)/kukury lange (the mimic weed)[dog's tail]
III	**Identified**	
1.	**a specific word** (most crop has several specific names called by each language group)	madua (*E. coracana*)/khadua (*E. indica*) gruji suau (*Echinochloa frumentacea*)/dhera (a weed, *E. colona*) merendo, kodowar (a mimic weed, *P. scrobiculatum*)/matwali, kharasami (a weed, *Paspalum sp.*)
2.	**added a few adjective words**	
2.1	**meaning "weed"**	lingudi (*Setaria pumila*)/ghas lingudi (the weed) kodo/kodo ghas,
2.2	**like "another crop"**	same melatti (a mimic weed, *B. ramosa*) [like little millet] akki hullu (a mimic weed, *P. sumatrense*) [weed like rice]
2.3	**indicating a morphological trait**	ragi kaddi (a weed, *E. indica*) [finger millet with spike like a stick] bilai lange (a weed, *S. pumila*) [cat's tail]
2.4	**indicating an ecological trait**	samulu (*Panicum sumatrense*)/yerri arasamulu (the weed with grain shattering) same (*P. sumatrense*)/samuru korra (*S. pumila*) [foxtail millet growing in little millet field] varagu sakkalathi (*S. pumila*) [a mimic weed, second wife of kodo millet] sakkalathi same (a mimic weed, B. ramosa) [second wife of little millet]
2.5	**indicating a utility**	same (*P. sumatrense*)/ pil same (*Brachiaria ramosa*) [for fodder],
IV	**Classified into some landraces**	marua (*E. coracana*): three varieties; agat- [early], madhyam-[medium] and pichhat-[late] /maruani (E. indica). sama (*P. sumatrense*): four varieties; manchi-[summer], pala-[short], ara-[tall] and varagu-[sowing in January].

Domestication Process of millets

Human beings had domesticated more than 30 grass species, as cereal crops, in several parts of the world, for example, *Hordeum vulgare* had been domesticated possibly as long as 12,000 years ago. However, several species are threatened and in spite of their potential food value in their native habitats, have disappeared or have hardly been cultivated. This is because the three major crops of wheat, rice, and maize have rapidly increased in their yield and production, due to huge technical innovation in crop improvement programs. The other grain crops, that is to say, millets, have decreased gradually during the previous century, resulting in genetic erosion of their local varieties. Today, we need recognize their value as exploitable and underutilized genetic resources, based on their adaptability to stress-prone environments. These species of millet are mostly C_4 plants, which are early to mature, and can be cultivated under conditions of severe drought and harsh sunlight.

Local farmers continue to cultivate a few useful varieties of millet even today. These indigenous varieties are excellent materials for investigating crop evolution, particularly the origin and dispersal route of domesticated plants. In the Indian subcontinent, a few small millets are still undergoing the domestication process (Kimata et al. 2000; Singh and Arora 1972). While crop evolution can be reconstructed mostly from botanical data, the aspects of geographical origin and dispersal will become clear from the information on the agricultural basic complex offered by local farmers.

Vavilov (1926) showed the domestication process from weeds associated with wheat to the secondary crops in two genera, *Avena* and *Secale*. For example, *Secale cereale* L. had built up strong resistance to cold in high altitude and/or latitude areas, and, subsequently, this species had been able to grow under more severe conditions than those under which wheat can grow. Kobayashi (1987, 1989) proposed an integrating model of the domestication process of Indian millets as secondary crops from mimic companion weeds associated with *Oryza sativa* L.

O. sativa had been spread first from wetlands to uplands, secondarily, in the Indian subcontinent. Their ancestral weedy plants had invaded paddy and upland rice fields in turn. These are *Panicum sumatrense* Roth. (little millet), *Paspalum scrobiculatum* L. (kodo millet), *Echinochloa frumentacea* Link (Indian barnyard millet), *Brachiaria ramosa* (L.) Stapf. (korne), *Digitaria crusiata* (Nees) A. Camus (raishan), and *Setaria pumila* (Poir.) Roem. & Schult. (korati; syn. *S. glauca* (L.) P. Beauv.) (Chandra and Koppar 1990; de Wet et al. 1983a, b, c). *Pas. scrobiculatum*, *P. sumatrense*, and *E. furumentacea* were subsequently domesticated by local farmers as secondary crops to upland rice, because these had put up stronger resistance to drought than upland rice in Eastern India. In this region, several species of millet were domesticated.

S. pumila is a weedy annual growing 30–60 cm tall. The inflorescence is cylindrical, densely flowered, spike-like raceme, 2.5–10cm long, usually yellow, or more rarely purplish or pale green. It is a fairly common grass, especially in cultivated lands, along the roadsides, and in cleared forests, up to altitudes of 700 m. The spikelet (c.a. 3-mm long) is pale green or brownish-green. Cattle are fond of it (Achariyar 1921; Singh 1988). *S. pumila* is a multiple polyploid species (2n=18, 36, 72) and an unknown genome constitution (almost genome D) (Zhao et al. 2013). The present paper is concerned with the tertiary domestication process of *S. pumila* through the mimicry that is related ecologically and genetically to the relative weeds and several grain crops in the Indian subcontinent.

The domestication process of *S. pumila* may have passed through four steps as illustrated in Figure 41. The first step consisted of a weed that had grown along roadsides and other unstable habitats moving to invade upland rice fields. The second step was an evolutionary process of

obtaining an agro-ecological niche as use for fodder, to attain companion weed status in upland rice and millet fields. The third step was a process of advancing from mimic companion weed status to a semi-domesticated insurance crop in case of famine, under mixed cropping with *P. scrobiculatum*, *E. coracana*, and *P. sumatrense*. After their invasion into upland rice and millet fields and under the severe weed control measures practiced by farmers, weeds evolved to mimic particular crops and to create a close weed-crop complex. In the third step, farmers reduced the aggressiveness of their weed-control practices. In the fourth step, mimic companion weeds were used as both a fodder source for cattle and as a supplementary grain to the main cereal species. In the case of *S. pumila*, overly strict weeding was avoided as a means of crop insurance in years of extreme drought in the Deccan. This may have led to *S. pumila* growing taller with larger spikes and seeds accompanied by less shattering, and gradually progressing towards domestication. *S. pumila* has obtained mimetic traits such as a long leaves, a few tillers, and tall height, in fields of *P. sumatrense*. The pigmentation of leaves and leaf sheaths by anthocyanin creates the mimicry among grain crops and closely related weeds in mixed crop stands (Kimata 2015a, Kimata et al. 2000).

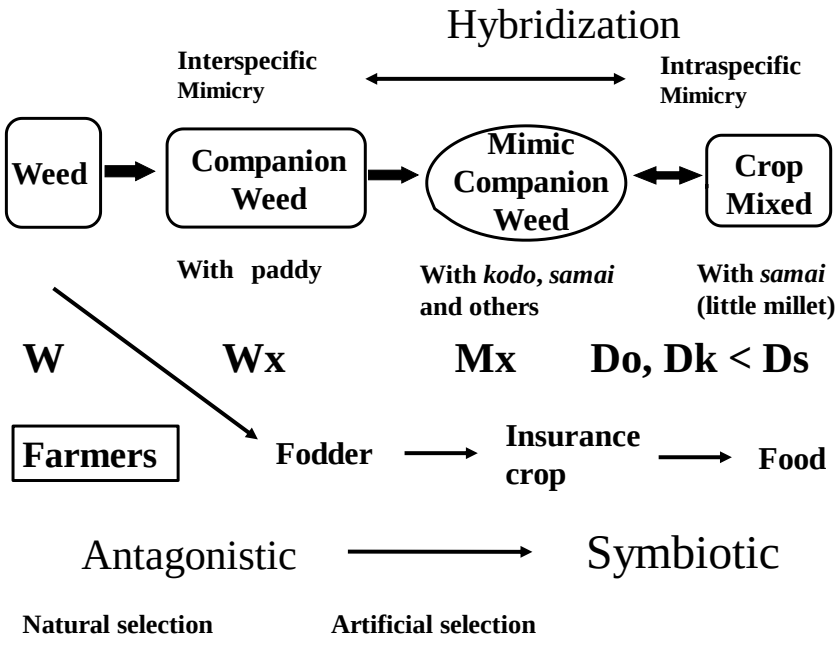


Figure 41. Domestication process of *S. pumila* in relation to the weed-crop complex.

S. pumila concurrently diversified its traits entirely through hybridization among the four types under natural and artificial selection in severely arid environments. Mimic companion weeds were harvested together with other (crop) millet, and were sown again involuntarily the following season. Recently, at the fourth step, this situation was followed by mixed cropping. *S. pumila* is termed a

"tertiary crop" in relation to its associated plants, secondary crops such as *P. sumatrense* and *Pas. scrobiculatum*, with respect to rice. The domestication process of *S. pumila*, a tertiary crop mixed with other grain crops, proceeds from inter- and intraspecific mimicry by natural and artificial selection in sympatric fields. This process has occurred by adaptation to aridity as a result of the spread of *S. pumila* from the east to the south in the Indian subcontinent.

Archaeology of millets

Recently, archeological studies have shown very useful data in the Indian subcontinent (Table 37). The material of millet grasses came from archaeological levels, Phases II (2300–1800 cal. BC) and Phases III (1800–1200 cal. BC) in the Southern Neolithic chronology. They have been identified as being primarily from two species, browntop millet, *Brachiaria ramosa*, and bristly foxtail millet-grass, *Setaria vercillata*. Yellow foxtail millet, *Setaria pumila* was present in limited quantities, possibly gathered from the wild (Fuller et al. 2001). The first occurrence of cereals in the Harrappan Civilization had been wheat, barley, and oats in the Early phase (before 2600 BC); *Eleusine* sp. (problematic, *E. coracana*), *Setaria* sp., and *Panicum* sp. in the Mature phase (2600–2000 BC); and *Paspalum* sp., *Echinochloa* sp., *Sorghum* sp., and *Pennisetum* sp. in the Late phase (more recent than 2000 BC) (Fuller and Madella 2000; Weber 1992).

Table 37. Summary on the first occurrence of grain crops in South Asia

Species / Period	Early 4500 B.C.–	Mature –2600 B.C.	Late –2000 B.C.	(South India) 2300–1800 B.C.	(South India) 1800–1200 B.C.	–0 A.D.	1500 A.D.	1900 A.D.
Paspalum scrobiculatum					trace			
Panicum sumatrense				trace	a few			
Echinochloa cf. colona					many			
Brachiaria ramosa			wild?	many	many			
Setaria verticillata			wild?	many	many			
Setaria pumila			wild?	trace	trace			
Setaria sp.			a great many					
Digitaria cruciata								domesticated
Digitaria sanguinalis							(unknown, disapeared)	
Panicum miliaceum		a few						
Panicum sp.			a few					
Setaria italica			possible					
Eleusine coracana			?	possible				
Sorghum bicolor			many					
Pennisetum glaucum			trace	trace	trace			
Coix lacryma-jobi						possible		
Oriza sativa		many		trace	trace			
Hordeum vulgare	a great many			many	many			
Triticum dicoccum				trace	trace			
Triticum durum/aestivum				many	trace			
Triticum sp.	a great many			many	many			
Avena sativa	a few							
Zea mays								introduced

Modified and Based on Fuller et al. 2001, Fuller and Madella 2001, and Fuller (personal communication).

Dispersal routes of millets in the Indian subcontinent

Our team studied the domestication process and dispersal routes of Indian millets. An outline of the research results is given below.

Kodora, *Paspalum scrobiculatum*, was domesticated since about 2000 BC in India. This species

is cultivated throughout the Indian subcontinent, but mainly in Madhya Pradesh. Ecological and morphological characteristics were compared using 32 accessions (including weed forms) of *Paspalum scrobiculatum*. In addition, the relationship between plant pigmentation and mimicry of rice was observed in 16 accessions, including six accessions collected from upland rice fields. Domestication process of the secondary crop to upland rice was discussed (Ishikawa unpublished). This species shifted from perennial to annual and obtained crop-like traits by accessions with rice cultivation. Both amplified fragment length polymorphism (AFLP) analysis and nucleotide sequence variation of the chloroplast trnK/matK region divided cultivated accessions into two groups, northern and southern groups. The northern cultivated accessions were genetically related to weed accessions collected from upland rice fields in Orissa. However, southern cultivated accessions showed close relationships to both accessions of upland rice fields in Orissa and the weed type in southern states. Furthermore, two alternate hypotheses for the origin of *Paspalum scrobiculatum* were summarized: (1) kodo millet was domesticated once in Orissa and then diffused to inland and southern states and (2) kodo millet was domesticated in Orissa and somewhere in the southern states of India, independently (Ishikawa 2007).

Jangora, *Echinochloa furumentacea*, is cultivated for food, fodder, and as an emergency crop in India, Nepal, and Pakistan. Its ancestor is a weed, *Echinochloa colona*, found in paddy fields. Morphological characteristics and AFLP analysis results of seven accessions of *Echinochloa colona* and 42 accessions of *Echinochloa furumentacea* were compared. On the basis of the results, the place of origin was assumed to be around Bihar, and then it was distributed to Tamil Nadu via Karnataka (Kagami unpublished).

Samai, Panicum sumatrense, is cultivated for food and fodder in India, Nepal, Sri Lanka, and Myanmar. Its ancestor is a weed, *Panicum sumatrense* subsp. *psilopodium*, found in paddy fields. Morphological characteristics and AFLP analysis results of 38 accessions and 281 herbarium specimens of *Panicum sumatrense* were compared. On the basis of the results, the place of origin was assumed to be Eastern India, and it was then distributed in Southern India (Otsuka unpublished).

Korne, *Brachiaria ramosa*, is grown by very extensive farming for food in only India. Its ancestor is a weed found in paddy fields. Morphological characteristics and AFLP analysis results of 70 accessions of *Brachiaria ramose*, including both weed and domesticated types, collected from Pakistan and India were compared. On the basis of the results, the place of origin was assumed to be the southern part of Orissa, and it was then distributed in the Deccan Plateau via Tamil Nadu (Otsubo unpublished).

Korati, *Setaria pumila*, is a cosmopolitan weed, but its domesticated type is mostly grown by mixed cropping with *Paspalum scrobiculatum* or *Panicum sumatrense* in only India (Kimata et al. 2000). This domestication process is discussed in detail below.

The integrating hypothesis for the dispersal route of Indian millets is illustrated in Figure. 42 on the basis of the results. *Echinochloa furumentacea*, *Panicum sumatrense*, and *Paspalum scurobiculatum* were secondary crops to upland rice. First, their ancestral plants were companion weeds derived from the relative weeds that invaded paddy fields in humid regions of Eastern India. Second, the companion weeds became insurance crops in upland rice fields, and they spread to a dry region in the Deccan Plateau (Kobayashi 1987, 1989). *Brachiaria ramosa* and *Setaria pumila* were so called ‘tertiary crops’ because they were secondary crops to other millet species domesticated

from their relative weeds in upland fields. On the other hand, *Digitaria cruciata* has been recently derived from the relative weed grown in maize or vegetable fields, Kashi Hill, Meghalaya, and is limited to the same area (Singh and Arora 1972).

Tentatively, Indian millet species were domesticated in the process of diffusion from humid paddy fields in Eastern India to dry upland rice fields in the Deccan Plateau, Southern India.

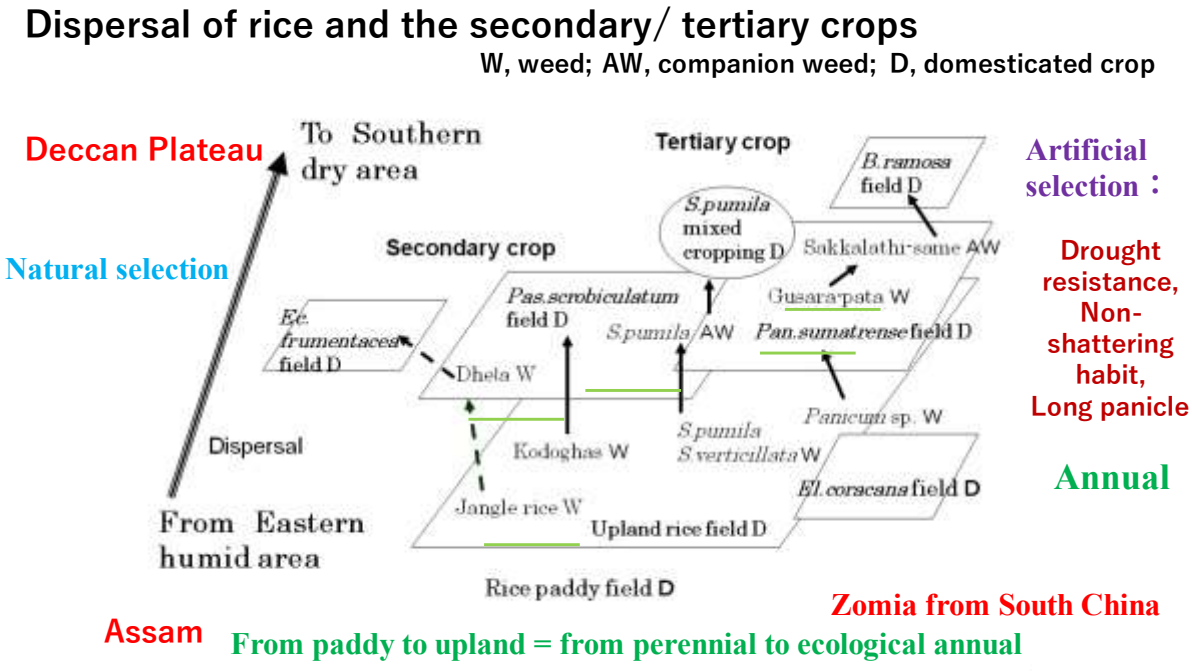


Figure 42. Domestication process of millets in the Indian subcontinent

In conclusion, the domestication process of millets based on field observations (Kimata et al. 2000), experimental results (Kimata 2015a, 2015b), and these linguistic sources is illustrated in Figure 42. This domestication center of millets covered the Eastern Ghats and Southern Deccan Plateau. Although this process is quite complicated among millets and their relatives, it is very effective for understanding the domestication by a secondary origin via weed and mimic companion weed types. Oats and rye were the secondary crops of wheat that developed cold tolerance (Vavilov 1926), while Indian millets were secondary crops of upland rice that developed drought tolerance. *Bachiaria ramosa* tolerates drought better than *Setaria pumila*, and it became an independent crop. *Setaria pumila* is almost always grown with little millet, but it seems to grow singly when little millet fails to grow in severe droughts. Both species are so-called tertiary crops, meaning, they are a double secondary crop for the other millets and upland rice. The millet domestication process indicates the importance of weed–crop complexes and basic agricultural complexes as a plant–man symbiosis.

Chapter 6　Food processing and cooking methods of seed grains

The cereals including millets have formed staple food since ancient times throughout Eurasia. Among millets, common (proso) millet and foxtail millet have been cultivated in areas covering almost the whole oof Eurasia. According to archaeological evidence, these two millets are considered to have been used as the staple food of Neolithic Yan-Shao people of North China and cultivated in Neolithic villages all over Europe through the four millennium B.C. (or 8500 B.P. as another opinion, Jones 2004). These cereals got dispersed from their domesticated regions through the Eurasia land mass during pre-historic and historic ages. Human ancestors had accumulated the cultural diversity based upon the natural diversity on the earth. The civilization has been supported radically by the basic agricultural culture complex which is one of main principles of culture. The processing and cooking of millets are an integral part of this complex as well as the cultivation practice. Therefore, the botanical study on domestication process is supplemented and supported with the comparative study on processing and cooking to help to clarify the geographical origin and dispersal of a given millet (Kimata and Seetharam 1997).

Japanese cooking has developed under the influence of Chinese, Indian, and African agricultural culture complex. Many basic traditional elements of millet processing and cooking methods are found in Japanese methods for cooking grains. Even today, the millet is also a very important crop in semi-arid and mountainous regions including Japan for future utilization.

Generally speaking, the utilization methods of cereal grains are divided into two groups, one for foods and the other for drinks. The former is furth divided into two groups, one for foods and the other for drinks. The former divided into three categories, grain, meal and flour, and the latter into non-alcoholic and alcoholic drinks. Since ancient times many traditional foods and drinks have been made from common millet and foxtail millet extensively in many parts of Eurasia. The preparations of boiled grain, gruel, *mochi* (in Japanese), and alcoholic drinks are popular in East Asia; while meal porridge, bread and non-alcoholic drinks prevail in Southeast Asia and Europe.

The basic processing methods are shown in Figure 43. Our ancestors had caught fire in ancient times, and then their civilization had become developed quickly. Wrangham (2009) summarized as follows.

C. Darwin cooked with hot rocks in an earth oven and called the art of making fire “probably the greatest [discovery], excepting language, ever made by man.” He understood the value of cooked food. But he showed no interest in knowing when fire was first controlled. His passion was evolution, and he thought fire was irrelevant to how we evolved. Most anthropologists have followed Darwin’s assumption that cooking has been a late addition to the human skill set, a valuable tradition without any biological or evolutionary significance.

A century later, cultural anthropologist C.L. Lévi-Strauss produced a revolutionary analysis of human cultures that implicitly supported the biological insignificance of cooking. He was an elite anthropologist, and his implication that cooking had no biological meaning was widely touted. No one challenged this aspect of his analysis. However, the cerebrated French gastronomist J-A Brillat-

Savarin (wrote in 1825) sounded evolutionary. “It is by fire that man has tamed Nature itself.” After our ancestors started cooking, he argued, meat became more desirable and valuable, leading to a new importance for hunting. Cooked food does many familiar things. It makes our food safer, creates rich and delicious tastes, and reduces spoilage. Heating can allow us to open, cut, or mash tough foods. But none of these advantages is as important as a little-appreciated aspect: cooking increases the amount of energy our bodies obtain from our food. We should indeed pin our humanity on cooks. We are tied to our adapted diet of cooked food, and the results pervade our lives, from our bodies to our minds.

This theory proposed by Wrangham (2009) is applied to not only meat but also cereals. Nakao (1972) had written as follows. The issues of processing and cooking have been studied only a little. It was very hard to understand that researchers had been indifferent on processing and cooking. These methods are very important parts in the agricultural culture complex.

There are countless cooking experts everywhere in the world. They have created a huge number of recipes which are brilliant and delicious. On the other hand, I am very interested in the basic and radical processing/cooking methods, that is, such dawn of basic agricultural culture complex including processing/cooking methods as Nakao’s hypothesis (1967, 1972). However, Nakao (1972) had recognized that rice had domesticated in Eastern India. At the present, rice had been domesticated around Peal River in South China based on the detailed results of genetic analysis (Xuehui Huang *et al*. 2012). Therefore, we have need to reconsider his excellent theory on the agricultural culture complex, especially about the dispersal of processing and cooking methods. It has very great reversal on the domestication process of rice and Indian millets companied secondary with rice too.

Processing methods of seed grains

We have two special ways of parboil processing and wet milling methods. Farmers boil the grains of Japanese barnyard millet in Japan, and little millet etc. in India before the de-husking. After the parboiling, we can easily de-husk small grains of millets. They make the flour of grains through the wet milling process to daily use and the offering for their gods in Japan and India. It means that some millets are sacred crops like rice and they are the same status both in Japan and India.

The milling process is done by two methods; dry milling and wet milling. Most grains are made into flour through dry milling method. In rare cases wet milling method is adopted for preparing flour.

Millet cooking was dispersed from the original domesticated zone to various areas together with its cultivars (seeds), their cultivation (tools and techniques), the food processing of seed grains (tools and technique), and the other utilities. In the traditional food processing the parboiling method and wet milling method (*shitogi* in Japanese) are important particularly to clear up the historical relationship between the processing method and domestication process. The parboiling method may be considered as one of the oldest processing techniques of millets and rice grains.

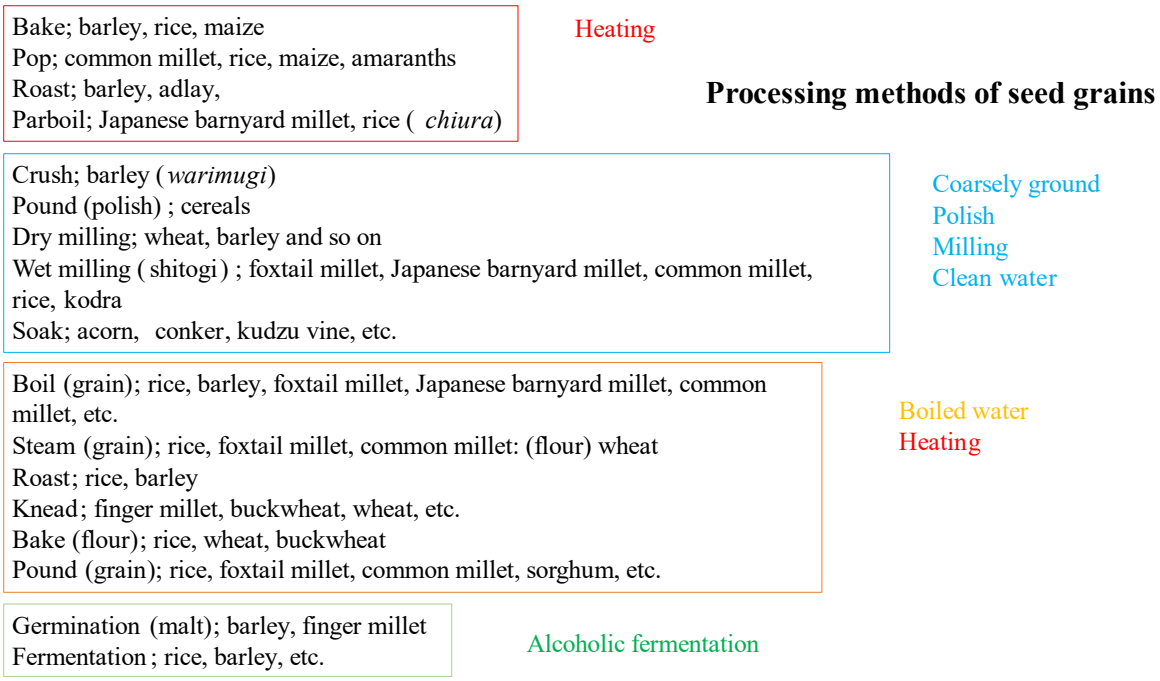


Figure 43. Basic processing methods of seed grains

Wet milling method and flour foods

In Jomon period, our ancestors had gathered many kinds of nuts for food in Japan, for example, *Quercus serrata* (Figure 44a), *Castanopsis sieboldii* (Figure 44b), *Castanea crenata* and so on. Because these nuts are generally bitter, they had removed bitterness by much volume of water in a stream. They had made flour from nuts by water bleaching method. Moreover, our ancestors had collected flour from *Dioscorea* spp., taro, sago palm and so on (Nakao 1967). Jomon people had become easily to get much food materials, and then they had obtained their stable life. Afterwards this water bleaching method could have influenced to *shitogi*, wet milling method of seed grains (Figure 45 and Figure 46).

Figure 44. Nuts, parched grains and barley/wheat fields

a, *Quercus serrata*; b, raw edible nut, *Castanopsis sieboldii*; c, roasted rice; de, roasted barley; f, barley fields; g, a wheat field mixed with many kinds of weed at the Botanical Garden of Free University of Berlin.

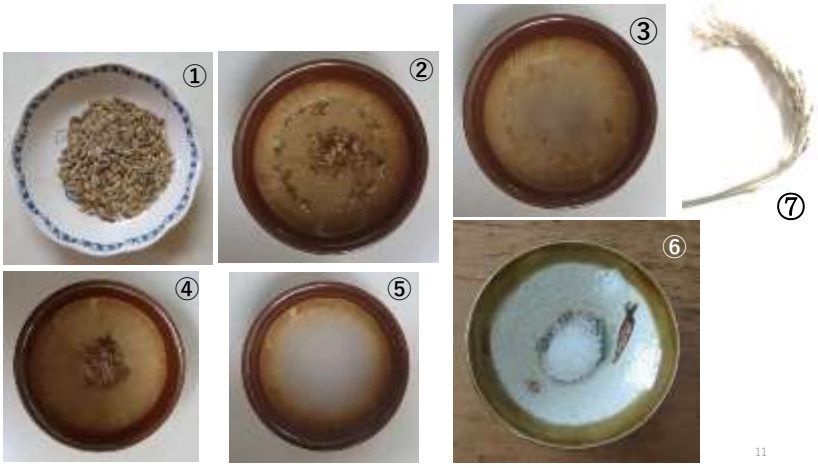


Figure 45. Wet milling method, *shitogi*

①upland rice grains; ②soaking; ③④⑤pounding and removing hull; ⑥drying up *shitogi* flour; ⑦ panicle of upland rice.

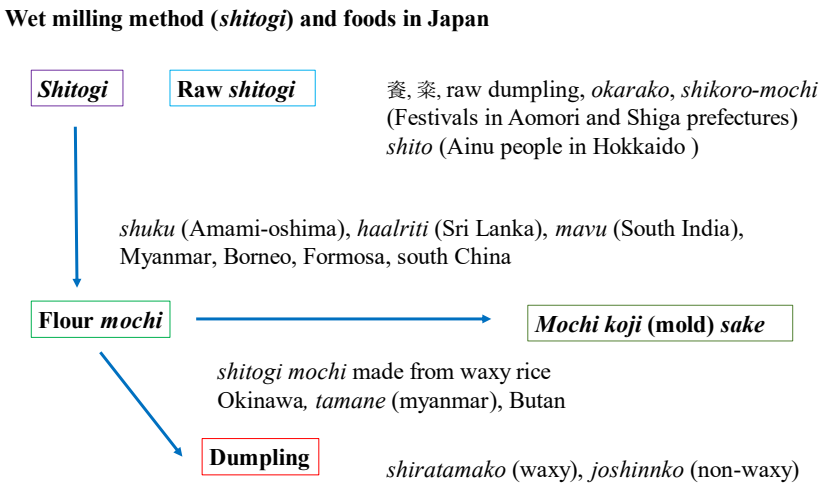


Figure 46. Wet milling method (*shitogi*) and foods in Japan

Kona-mochi (flour) and *Koji-sake* were derived from *shitogi* as shown in Figure 46. Ainu people have made *shito* from some kinds of millet in order to offer it to their god *Kamui* (Figure 47 and 48). The same food had called *shitogi* in Aomori, *shuku* at Amami-oshima, Kagoshima, *shutonpa* made by children at koshiki-jima and generally *nama-dango*, *okarako* or *shikoro-mochi*, etc. (raw dumpling for offering to gods). Villagers have used *shitogi* (raw rice flour) at the festivities.

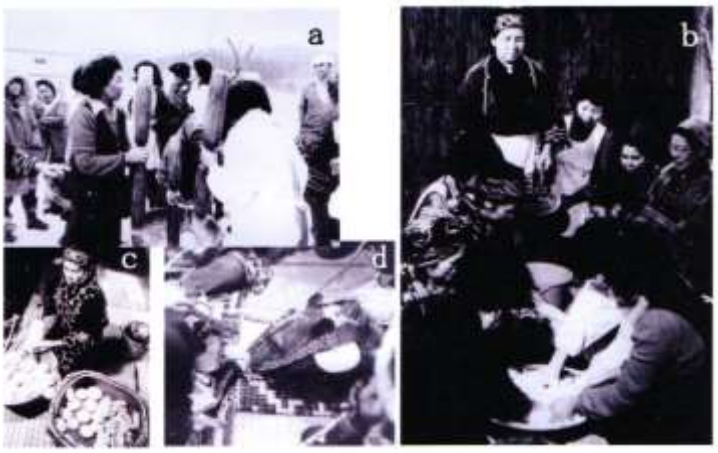


Figure 47. Ainu people have made *shito* from foxtail millet and common millet

a, pounding the polished grains by mortar and vertical pestle; b, kneading flour by hands; c, shaping to disc; d, offer up *shito* to gods *Kamui* through a bear which is the messenger. (Photographs permitted by Kaizawa.)

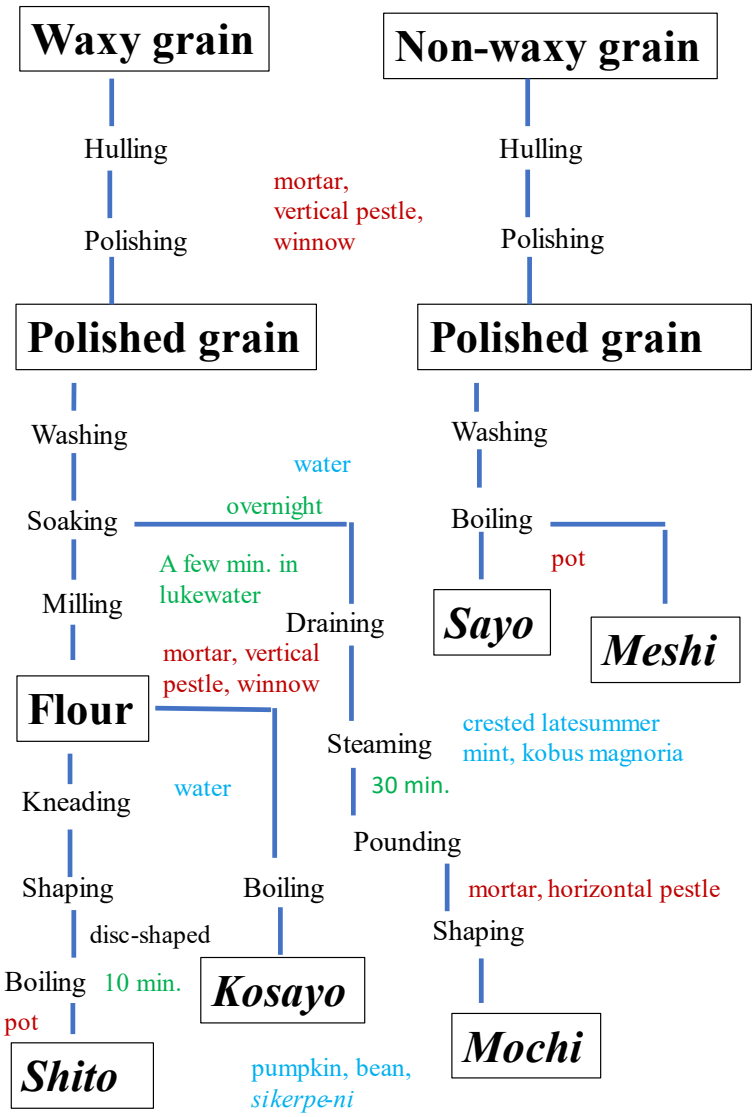


Figure 48. Cooking methods of foxtail millet in Saru river bioregion, Hokkaido

Shitogi had been made from Japanese barnyard millet, foxtail millet, common millet and rice. Ainu people have grown two varieties of Japanese barnyard millet. One is Ainu-bie, and another is Nanbu-bie as shown in Figure 49.

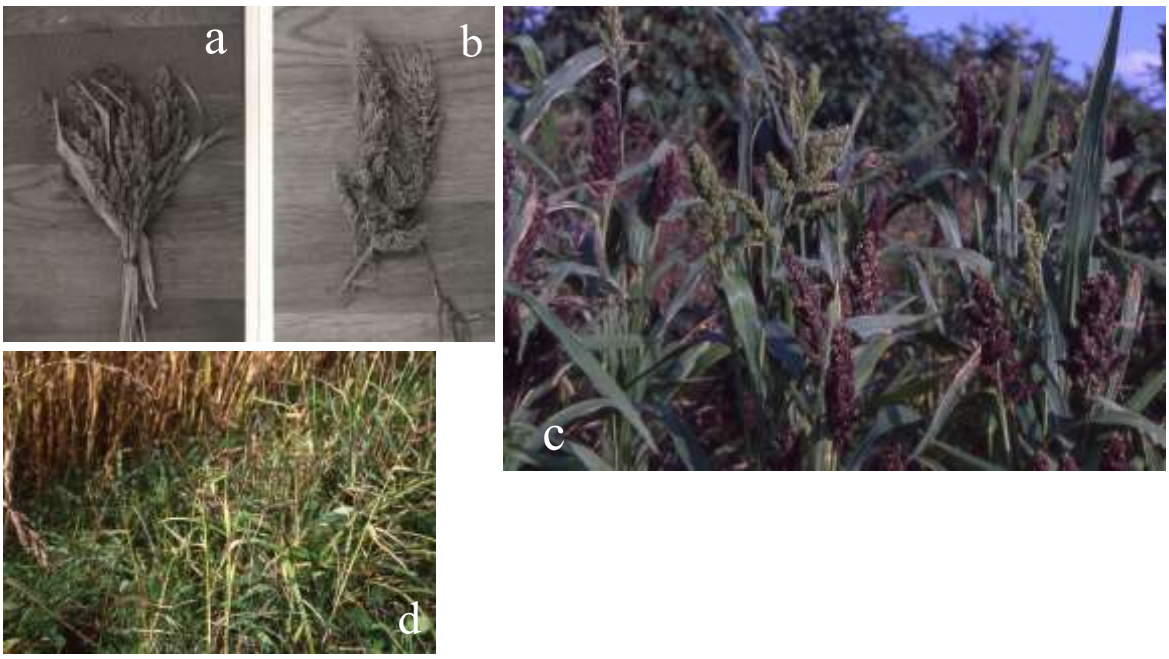


Figure 49. Japanese barnyard millet, *Echinochloa utilis* in Hokkaido, Japan

a, Nanbu bie; b, Ainu bie; c, Nanbu bie on a farm; d, *Echinochloa crus-galli* on a levee of paddy field.

Nakao (1972) had written that he had not seen the food like *shitogi* in India. However, *mavu* in Tamil Nadu, India is a raw flour ball mixed with sugar and honey, and is homologous to *shitogi* in Japan. It is made from the flour of foxtail millet in several villages in Tamil Nadu, as shown in Table 38. This food is offered to the gods and goddesses and then eaten by villagers. *Pidimavu* made from rice flour mixed with *ghee* is a kind of taper offered to the gods and goddesses. The raw flour is made through a primitive method of milling Asian millets and rice using a pounding mortar for the wet milling method. There are many kinds of raw flour food not only in South India, but also in Sri Lanka, Myanmar, Thailand, Laos, Kalimantan, Formosa, South China and Japan.

For example, in Tamil Nadu, *mavu* (syn. *shitogi*) is made from foxtail millet（*S. italica*) and rice (*O. sativa*) for offering gods and goddesses. This wet milling method is a very interesting fact, as compared with the raw *shitogi* made from rice and some Asian millets in Japan. This rice flour is often cooked into *bonda*, a kind of fried ball in India, too.

Figure 50. Wet milling method of rice (same foods as *shitogi* in Japanese) in Andhra Pradesh

a, pounding rice grains; b, soke grains in water; c, dry and filtering; d, *pidimavu*, a kind of light offered for gods and goddess.

Table 38. Cereal cooking styles and their ingredients in Tami Nadu

Material/Cooking	sadamu	uppuma	chapathy	roti	nan	poori	vadai	dosai	idlai	kali	kulu	mavu	Total
Brachiaria sp.													0
Ec. frumentacea	○	△					○			○	○		5
El. coracana	△	○		○			□	○		□	○		7
H. vulgare		○		○				○	□	○	○		6
O. sativa	□	○					○	○		○		△	6
Pan. miliaceum	○	△					△			○	○		5
Pan. sumatrense	○	○					○	○		○	○		6
Pas. scrobiculatum	○									○	○		3
Pe. americanum	○			△						○	△		4
Se. italica	○	△					○	○		○	○	○	7
Se. pumila													0
So. bicolor	○	△		△			○	△		○	○		7
T. aestivum			○					○		○	○		4
T. dicoccum		○											1
T. durum		△	△			△							3
Z. mays		○					△			△	○		4
Total	9	11	2	4	0	1	8	7	1	12	11	2	68

Grain foods and parboiling method

The parboiled method may be considered as one of the oldest processing techniques for millet and rice grains. Most Indian millets and upland rice are frequently parboiled, especially in eastern India (Kimata and Sakamoto 1992). Almost all millets are parboiled before being consumed in Bangladesh. It is very interesting that parboiling developed and is still used in the area from India to Myanmar for domesticated strains of Indian millets and rice (Islam 1993; Muller 1988). About half of rice produced in India is parboiled. In western Africa rice has also been traditionally parboiled.

The method is thought to have diverse effects. First, the parboiled grains are protected from pests and molds, so they can be stored and eaten when needed. Secondly, through the parboiling

process, unripe juicy grains harvested too early become hard enough to hull and polish the grains (Nakao 1967). Thus, this method may have begun as a part of measures against the shattering of crop grains. Because shattering was common at the beginning stage of domestication, ancient farmers had to harvest immature ears before they ripened completely. When hunter-gatherers discovered this processing technique, the number of grains they could collect must have increased dramatically. After a traditional parboiling treatment in Japan, the glumes, lemmas, and paleas of *Echinochloa utilis* can be easily removed (Yabuno 1987). This process is also very useful for *E. furumentacea* and *Pas. scrobiculatum*, because these grains have multi-layer hulls (Malleshi and Hadiwani 1993)

Thirdly, the nutrients contained in the pericarp-testa permeate into the endosperm, the starch changes from a raw to pregelatinized, giving polished grains a high nutritive value, good flavour and the ability to be easily prepared and cooked (Achaya 1984, FAO1985, Malleshi 1989, Muller 1988). Through parboiling, a layer of gelatinized starch forms on the surface of the grain, and this prevents the nutrients from leaching out during boiling. This is a very important treatment in India, because boiled grain is cooked usually with the “draining off” method and the nutrients are thrown away with the excess boiling water.

This process probably has many effects on those grains. For example, through parboiling, 1) the unripe juicy grains become hard when a farmer has harvested the crop a little too early. This is done to escape shattering, so that the grain can then be easily dehusked and polished (Nakao 1967). In Japan, after parboiling of Japanese barnyard millet, the glumes, lemmas, and paleas can be easily removed (Yabuno 1987). 2) The nutrients contained in the seed coat permeate into the endosperm, the starch changes from a raw to a pregelatinized one, turning the polished grains into a very good condition (nutritive value, taste and easy cooking) for eating (Malleshi 1989). 3) The grains are protected from pests and mold, so that they can be stored and eaten when preferred.

Indian millets and upland rice are frequently processed by the parboiled method especially in East India as shown in Table 39, Figures 51 and 52. On the other hand, the other cereals, i.e., African millets, wheat, barley and maize do not need to be processed by the parboiled method because most of these cereals have naked grains except for the covered cultivars of barley. It is very interesting that the parboiled method, one of the oldest processing techniques, is now used in and around the domesticated areas of Indian millets and rice.

Table 39. Number of the cases processed by parboiled method in our survey of India (1985, 1987, 1989)

Species	Maharashutra	Madhya Pradesh	Maharashutra	Karnataka	Tamil Nadu	Andhra Pradesh	Orissa	Bihar	Total
Pan. miliaceum								4	4
Se. italica									0
Brachiaria ramosa									0
Ec. frumentacea							1	1	2
Pan. sumatrense				1	1		3	4	9
Pas. scrobiculatum				1			3	1	5
Se. pumila							1		1
O. sativa				2	2	1	3	7	15
El. coracana									0
Pe. americanum									0
So. bicolor									0
H. vulgare									0
T. aestivum									0
T. dicoccum									0
T. durum									0
Z. mays									0
Total	0	0	0	4	3	1	11	17	36

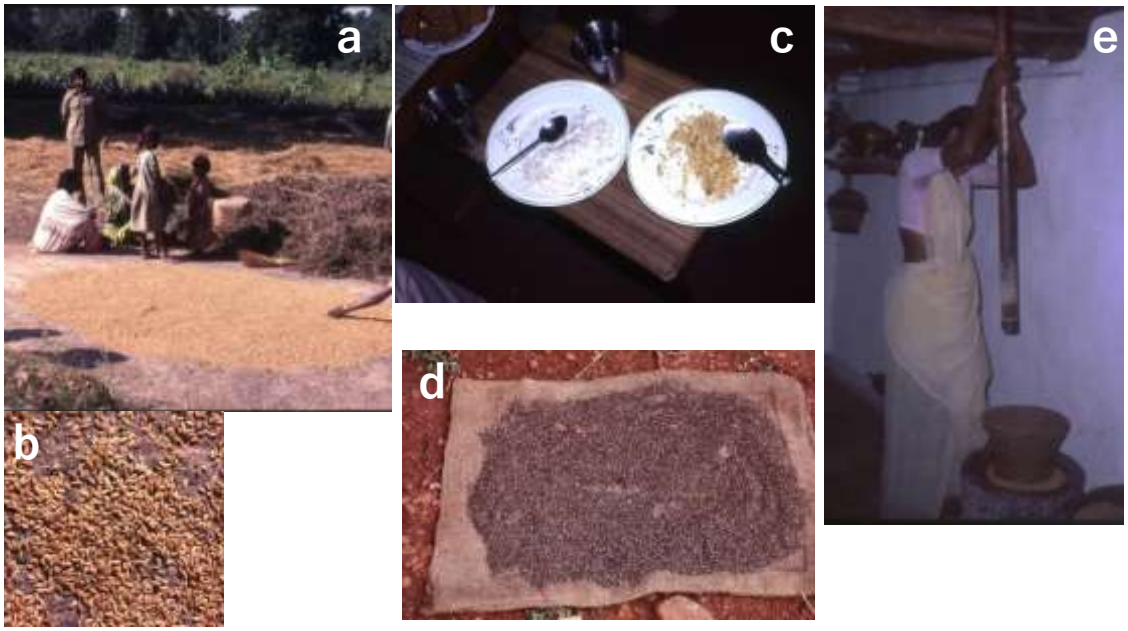


Figure 51. Parboiling method

ab, drying rice grains after boiling; c, *chiura*; d, drying *samai* grains after boiling; e, mortar and pestle for pounding foxtail millet.

Figure 52. Black steaming method of Japanese barnyard millet in Japan

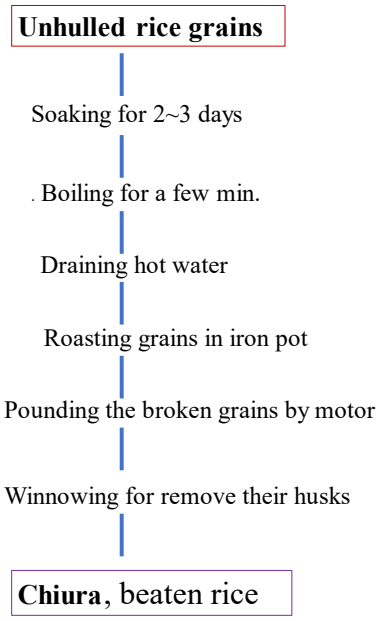


Figure 53. Chiura in India

The physical effect of parboiling for dehulling is shown in Table 40. Ketto TR200 was able to dehull *S. italica* and upland rice. As *E. utilis*, *P. miliaceum*, *Pas. scrobiculatum* and *S. pumila* had very smooth glume and lemma, TR200 was unable to dehull them, but Ketto Pearlest was tried. The parboiled unripe and ripened grains of *S. italica* and the parboiled unripe grains of upland rice were dehulled more easily than grains of their other lots and of the other millets and upland rice. The physical effect was indicated clearly only on *S. italica*, because the broken grain's ratio of both parboiled unripe and ripen grains after the dehulling process by TR200 were considerably lower than those of non-parboiled ones. For the other species, the parboiled grain was more or less broken easily, or did not show a difference among lots, especially when using Pearlest. The dehulling mechanism in TR200 is similar to that in a farmer's dehulling by mortar, while Pearlest has a different grinding mechanism that was mild enough to keep grains away from broken. The parboiling process showed an apparent effect on unripe and ripened grains of *S. italica*, and ripened upland rice grains. Thus, the parboiling process should be carried out as the method for preventing the shattering in ripened grains of these species. However, *S. italica* has not been parboiled traditionally. On the other hand, *Pas. scrobiculatum* has been traditionally parboiled in eastern India, as *E. utilis* has done in Japan (Kimata, M., S. Fuke, and A. Seetharam 1999).

Table 40. Effect of parboiling process on the dehulling and polishing of millet grains (20 g grains)

Species Lot	Hulled grains (g)	Broken grains (g)	Hulls (g)	Grains with hull (g)
TR200				
Setaria italica				
unripe grain	11.14	5.30	2.11	1.48
ripen grain	12.06	4.24	2.80	0
unripen grain parboiled	15.90	1.26	2.83	0
ripen grain parbouled	15.34	1.78	2.89	0
Echinochloa utilis				
unripen grain parboiled	0.14	0.79	1.22	17.85
ripen grain parbouled	0.05	0.86	0.59	18.50
Paspalum scrobiculatum				
ripen grain	2.56	3.40	4.43	9.61
ripen grain parboiled	2.16	4.34	3.61	9.89
Setaria pumila				
ripen grain	2.55	7.17	7.31	2.97
ripen grain parboiled	1.78	9.62	6.48	2.13
Oryza sativa				
unripen grain	11.08	1.54	4.42	2.95
ripen grain	13.37	0.39	3.63	2.61
unripen grain parboiled	12.66	1.12	4.34	1.88
ripen grain parboiled	13.12	0.64	3.58	2.44
Pearlest				
Panicum miliaceum				
unripen grain	15.77	0.13	4.11	not tested
ripen grain	15.52	0.28	4.29	
unripen grain parboiled	15.01	0.40	4.59	
ripen grain parboiled	15.10	0.18	4.71	
Echinochloa utilis				
unripen grain	14.32	0.12	5.56	
ripen grain	14.85	0.21	4.94	
unripen grain parboiled	14.38	0.12	5.51	
ripen grain parboiled	14.97	0.10	4.94	
Paspalum scrobiculatum				
unripen grain	13.04	0.04	6.93	
ripen grain parboiled	13.22	0.06	6.73	
Setaria italica				
unripen grain	11.96	0.29	7.75	
ripen grain parboiled	11.97	0.32	7.71	

The protein contents (%) in the grains of five millets and upland rice after dehulling or polishing grains are presented in Table 41. The grains of *E. utilis*, *Pan. miliaceum* and *S. pumila* contain protein more than 11 % of its dry weight, while *S. italica*, *Pas. scrobiculatum* and upland rice do around 7 %. The protein content of both unripe and ripe grains of *S. italica* increased somewhat through parboiling, but the content of *S. pumila* decreased remarkably. In *E. utilis* and *Pan. miliaceum*, the protein contents of unripe grains changed little through parboiling, while the contents in ripened grains decreased somewhat. *Pas. scrobiculatum* and upland rice showed little change in their protein contents through parboiling. Therefore, the parboiling method has no positive effect on the protein

contents of millets and upland rice except *S. italica*. Free amino acid contents increased in unripe grain of *S. italica* and ripened grains of rice through the parboiling process. Adenine nucleotide contents also increased in unripe grains of *S. italica*, *Echinochlooa utilis* and *Panicum miliaceum*, and ripened grains *Paspalum scrobiculatum* and *S. pumila* (syn. *S. glauca*). However, the parboiling process had no effect conclusively on the nutritive value of amino acid composition in grain proteins.

Table 41. Protein content (%)* of samples used

Species	non-parboiled grains				parboiled grains			
	unripe		ripen		unripe		ripen	
	hulled	polished	hulled	polished	hulled	polished	hulled	polished
Setaria italica	6.88	6.56	7.75	7.69	11.25	10.75	8.94	8.63
Echinochloa utilis	14.88	14.31	18.63	16.88	14.88	14.63	15.56	14.81
Panicum miliaceum	11.69	11.5	13.69	13.63	12.19	11.50	11.88	11.69
Paspalum scrobiculatum	not tested	not tested	7.44	7.38	not tested	not tested	8.00	8.00
Setaria pumila	not tested	not tested	13.13	12.19	not tested	not tested	6.63	6.38
Oryza sativa	6.75	6.69	7.19	6.88	6.56	6.25	7.44	7.31

* (N x 6.25) on dry basis.

Heating grains

Beaten rice (*chiura*, *chura*, *aval*) is expected to be thin, papery, friable and as broad in shape and as white in colour as possible. Paddy is soaked in water for 2 or 3 days till soft, and the same water is brought to the boil for a few minutes and cooled. The swollen grains are next placed in a concave iron or earthenware pan over a strong fire till the grains burst, after which they are pounded with a pestle to flatten the grain and remove the husk, which is thereafter winnowed away (Figure 53, Figure 54) (Nakao 1972, Achaya 1984). Nakao (1972) had written that *Yakigome* is the completely same food as *chiura*, but their cooking processes are different in boiling and parching (Kimata 1991, Nakao 1972). He added that this cooking method had been dispersed from India to Japan at very old times, and then it had disappeared in the intermediate region. Therefore, it had isolated in India and Japan.

In this case, I think that those cooking method had originated independently in Japan (Figure 44cde), and *Yakigome* had not dispersed from India. For example, Popcorn had been very old traditional food for the native American since 3600 BC. The basic cooking methods had been independently begun in many original places, but the conjoint cooking method had been made the agricultural complex with crops under their domestication process, and then it had been dispersed centrally from the original area by our ancestors.

Parched paddy (puffed rice, *muri* or *murmura*) is produced as follow. Parboiled rice is preferred for puffing, and the rice in handfuls is thrown into very hot sand held in *kadai* over the fire. The sand is turned around with a metal ladle, and as soon as the begins to swell and crack, the contents are poured off into a sieve; the puffed rice is collected, and the hot sand retrieved for reuse. Rice steeped in or roasted with salt water is used for parching in eastern India (Figure 54 and Figure 55ac). Commercial units consisting of roasting cylinders through which the rice travels in hot sand, which is sieved through and passes back into the cylinder, are now commonly in operation. White, glistening, plump grains are what the user expects of puffed rice (Achaya 1984). Japanese children

have called it *pakkan* or *ponsen*.

Laja (parched paddy) is a soft, light, whitish, commonly edible food product prepared by roasting paddy. According to Ayurvedic classics, Laja has *deepan*, *laghu*, *grahi*, *snneha*, *kapha-meda-chedak*, *balya*, *rasayan* and *ojo-vardhak* properties and it has been widely used as a remedy for *chardi*. Classical uses of Laja, its method of preparation, difference from parched rice, change in nutritive value during parching and its future research aspect (Awantika, J. et al. 2015).

Wheat that is specially broken, or emerges broken from threshing, is termed *dalia* and is used as a sort of boiled porridge. Like rice, wheat can also be puffed; the friable puffed product can be ground into a flour called *sattu* which being pre-cooked can be rapidly finished into various foods (Figures 54 and 55).

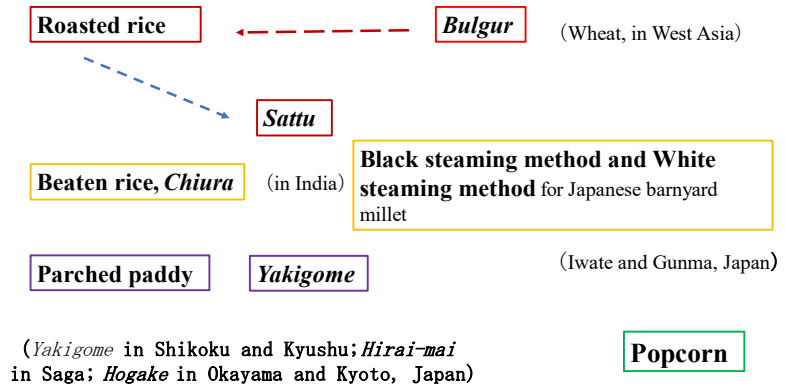


Figure 54. Heating grains by roasting, boiling, and parching

Figure 55. Parched grain of common millet

a, thrown into very hot sand held in *kadai*; b, *upitu*; c, parched rice grain.

Indian food culture

Indian food culture has been a reflection of the people's heritage. It represents India's historical

development, religious beliefs, cultural practices, and above all, geographical attributes (Sahni 1986). In the Indian subcontinent, staple foods made using grain crops are served with various types of spicy curries and legume *dal* stews (*dhal*). Many unique cooking styles can be found for each cereal in any part of the subcontinent (Aziz 1983, Sahni 1986). Cooking of cereals forms an important part of the agricultural culture complex (Maeshwari 1987, Sakamoto 1988).

Several species of millets have formed staple foods since ancient times throughout Eurasia. Especially among them, *Panicum miliaceum* and *Setaria italica* have been cultivated in areas covering almost the whole of Eurasia. According to archaeological evidence, these two kinds of millets are considered to have been used as the staple food of Neolithic Yan-Shao people of North China, and at the same time to have been cultivated in Neolithic villages all over Europe through the fourth millennium BC (Sakamoto 1987a, 1987b).

Foods made using millets

People have cooked many types of food using millets and cereals. Mainly *bhat* (*meshi* in Japanese), *roti* (*pan*), and *mude* (*oneri*) are cooked because they are frequently made using most of the cereals listed in Table 42 (Kimata 1987). *Bhat* is the most popular food, a boiled grain food made using all the ingredients shown in Figure 59ad. *Bhat* originated in ancient China and was brought to the Indian subcontinent via Eastern India. *Roti* is also a popular food made from cereal flour and originated from the cooking of wheat bread in the Fertile Crescent and was brought to the subcontinent via Western India. *Mude* is a popular food made from cereal flour and originated from the cooking of *ugari* brought from Eastern Africa via the Arabian Peninsula. Figure 59 shows cooking methods for cereals in the Indian subcontinent: (a) a traditional boiled rice with *papad* (crispy salted wafer made from *dal,* vegetables, and cereals); (b) *upma* and *kesari bhat*; (c) *dosa*; (d) *mude* and boiled grain made using *Brachiaria ramosa*; (e) *puli*; and (f) *idli*.

Table 42. Millets and their food in Indian subcontinent

Species name	Food								
	Indian name	bhat	upuma	roti	vada	dosa	idoli	mudde	ganji	mave
	Japanese name	meshi		pan	age pan		mushipan	oneri	konagayu	shitogi
Sorghum bicolor		○	○	◎	○	△	○	○	○	
Pennisetum americanum		○	○	◎				○	○	
Eleusine coracana		△	○	○	○	○	○	◎	○	
Setaria italica		◎	△	△	○	○		○	○	○
Panicum miliaceum		◎	△	○	△			○	○	
Panicum sumatrense		◎	○	△	○	○		○	○	
Paspalum scrobiculatum		◎		○				○	○	
Echinochloa flumentacea		◎	△		○			○	○	
Brachiaria ramosa		◎		○	○			○	○	
Setaria pumila		◎		△				△	△	
Digitaria crusiata		◎		○						

◎, main ingradient used; ○, generally; △, rarely or suppliment mixed.

Cooking methods of boiled grains

Anna is a kind of boiled grain and is homologous to the East Asian one, for example, *bhat*, *chawal*, *sadam*, *annamu*, etc. in India; *meshi* in Japan). As shown in Figures 56, 57 and 58 60, anna is made from crop grains in two ways, the “draining off” and parboiling methods in India, while it

is done by the “drying up” method in East Asia. The draining off method is a traditional one in India. The excess hot water when boiling grains is drained off, and thus grains become soft, non-sticky and flavour-full. Indian people like these characters of boiled grains. The parboiled method is maybe considered one of the oldest processing techniques for cereals, especially for millet grains. “Parboiled” means pre-boiling raw grains before polishing them. By this process the grain can easily polished, the nutrients contained in the seed coat permeate into the endosperm, and then the polished grains are in a very good condition for eating. Recently, some urbanized people in India cook rice with the drying up method, because they use rice-cookers to save time and to keep the nutritive value which is lost by draining off the excess hot water.

Anna is eaten with many kinds of curry, *dal*, *sambar* (a kind of spicy stew), *rasam* (spicy soup), pickles, yogurt, salt, plant oil, and so on. There are many variations of rice *anna*, for example *pullao* and *biryani* (rich *pullao*), which are special festival foods in India.

Figure 56. Anna (boiled grain; *bhat*, *chawal* etc.) in India:

a, cooking utensils to the hot water removal method; b, anna made from rice; c, *chawal* made from foxtail millet and sorghum in farmer’s lunch box; d, *chawal* made from *samai* (*Panicum sumatrense*); e, *chawal* on the thali; f, *ketsali bhat* made from rice and *upma* made from *Triticum durum*.

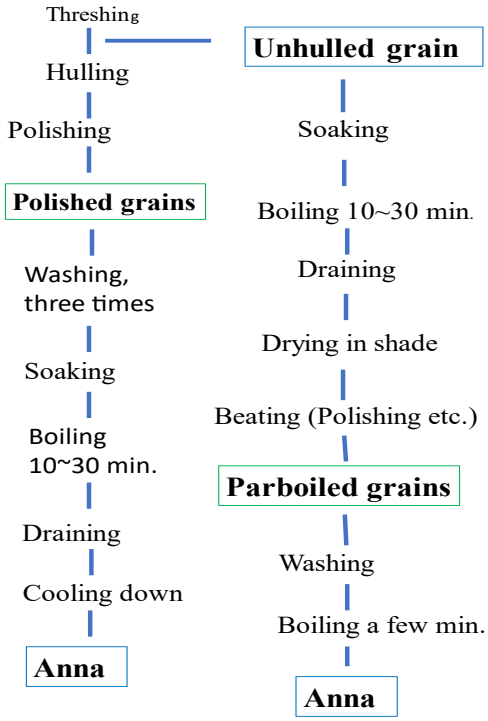


Figure 57. Cooking process of *Anna* (boiled grain) in South India

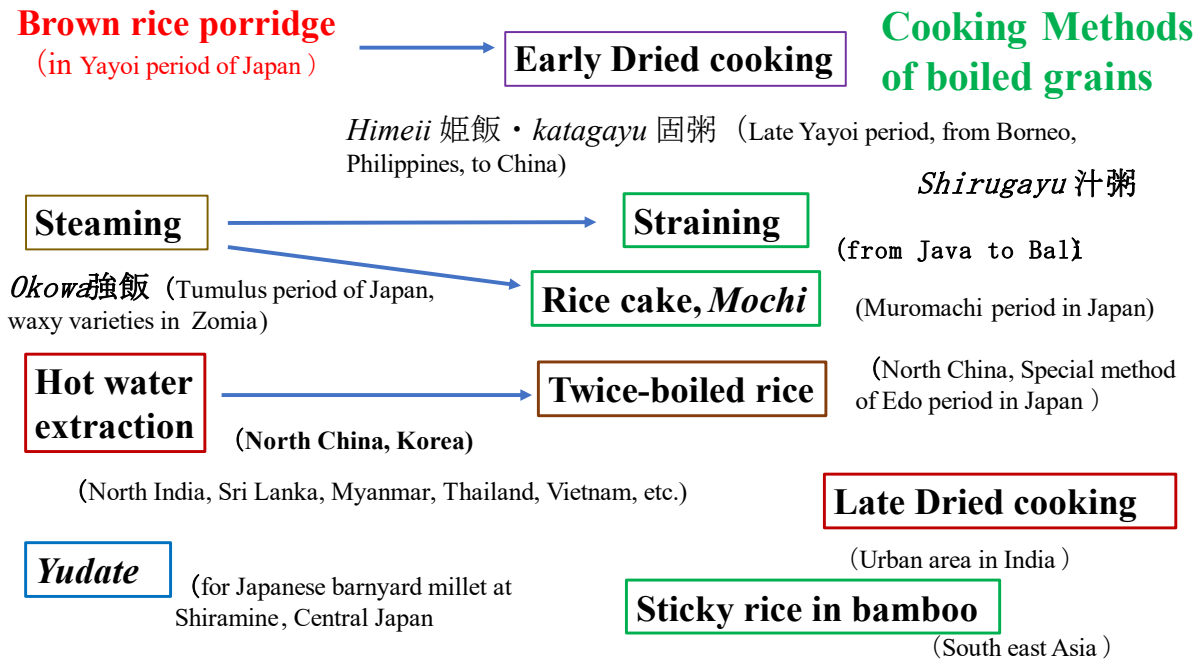


Figure 58. Cooking methods of boiled grains

Upma

Upma is made from ground coarse grains as shown in Figure 59b and Figure 60. This food is eaten mostly at breakfast. *Upma* is a spicy and nice smelling food which is mixed with chilli, ginger, ground nut, and yogurt or lemon juice

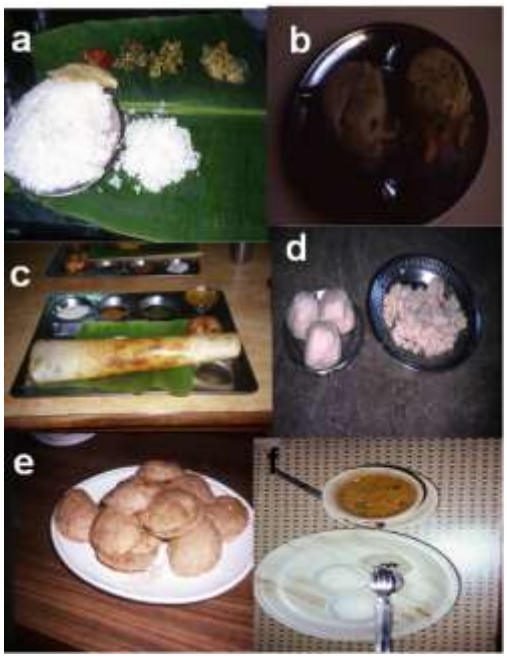


Figure 59. Cookeries of cereal in the Indian subcontinent:

a, a traditional boiled rice (*bhat*) with *papad*; b, *upuma* and *khesari bhat*; c, *dosa*; d, *mude* and boiled grain made from *Brachiaria ramosa*; e, *puli*; f, *idli*.

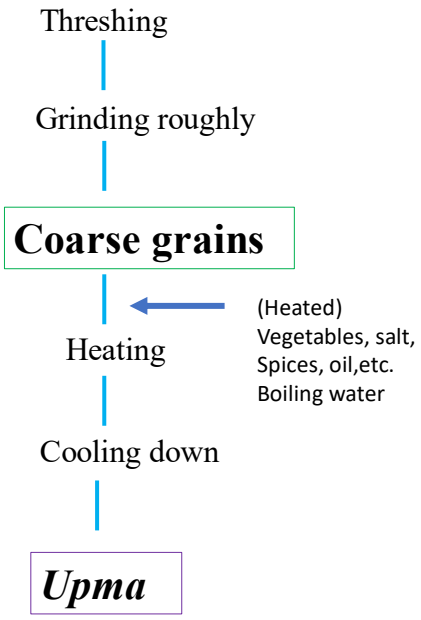


Figure 60. Cooking *upma*

Chapati, *roti*, and their variations

Chapati is the easiest form of Indian bread and the most familiar among the people (Aziz 1983). *Chapati* is an unleavened bread which is made from whole wheat flour as shown in Figure 62. Indian people wrap chapati in a dishcloth, and keep it warm in moderately heated oven before serving. They eat *chapati* with curry and dal stew (Figure 63a). The difference between chapati and roti is not clear. *Chapati* is called in some parts of India. In some other languages again, *roti* refers only to the loaf of bread bought from shops or delivered to the house from professional bakeries (Rangarao 1968). In this case the author temporarily calls the pancake made from whole wheat flour (*atta*) *chapati* and the others made from millet or bean flour roti.

Parautha is also a variation made from wholemeal flour, much thicker than *chapati* and lightly fried in oil (*ghee*). *Puri* is a deep-fried *chapati* (Figure 61c) and is traditionally eaten with *chenna* chutney made with whole chick peas at breakfast (Aziz 1983).

Nan is a semi-leavened bread made from fine wheat flour (*maida*) as shown in Figures 61a and 64. It had been introduced from West Asia in ancient times. Traditionally, *nan* is the perfect accompaniment to *tandoori* food, it is usually prepared in clay oven known as *tandoor* (Aziz 1983). Therefore, South Indian people seldom make *nan*.

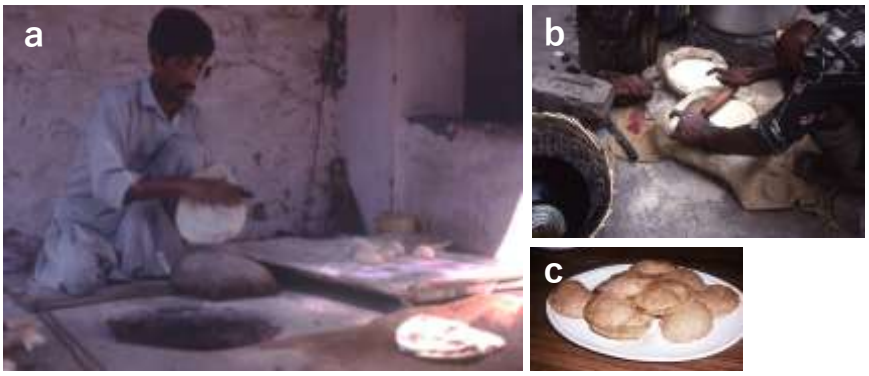


Figure 61. Food made from wheat, *Triticum aestivum*:

a, *nan*; b, *chapati*; c, *puri*.

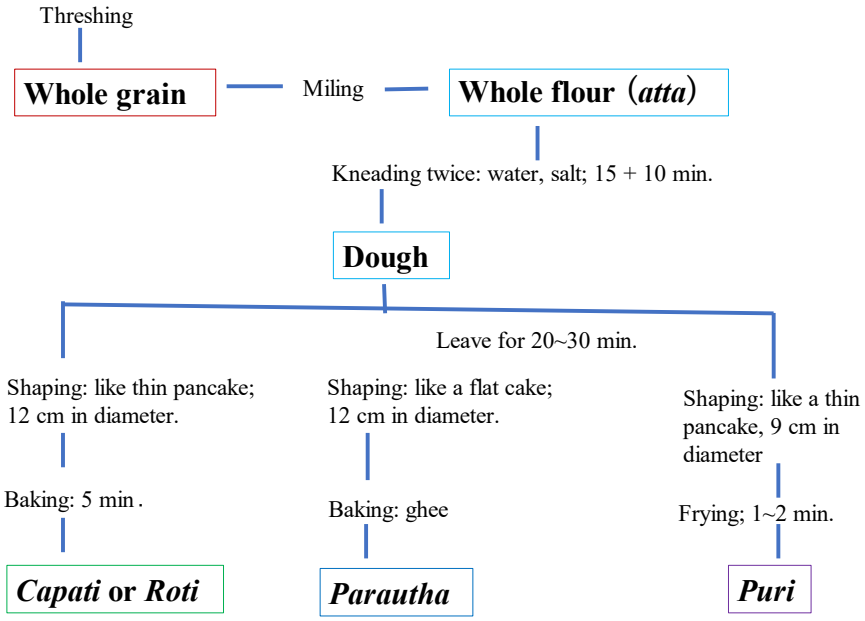


Figure 62. Cooking of *chapati, parautha* and *puri*

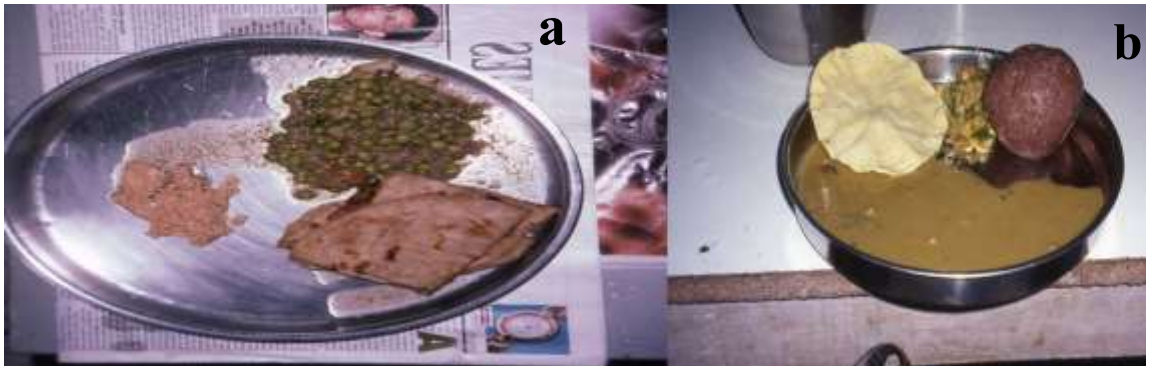


Figure 63. *Chapati* or *mude* on *Thali*

a, *chapati* from wheat; b, *mude* from finger millet, *Eleusine coracana.*

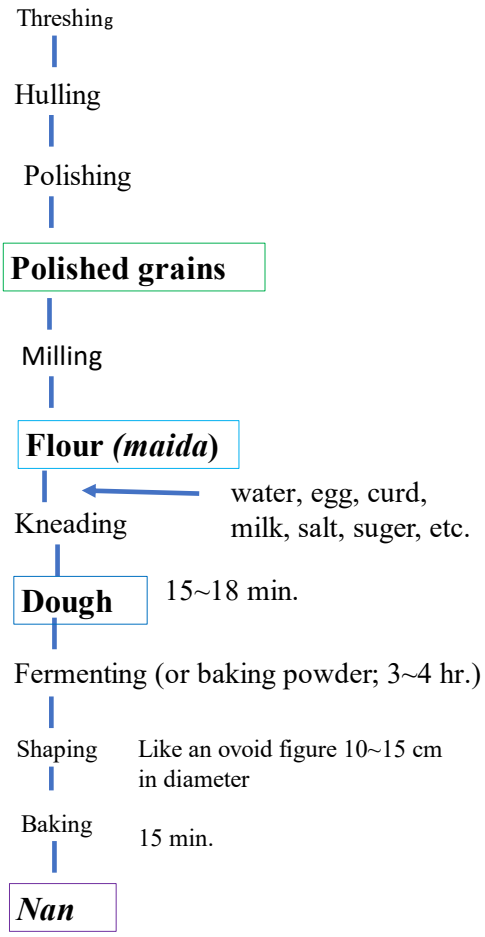


Figure 64. Cooking *nan*

Some other fried foods

Vada (*amavadai*) is a doughnut shaped or round flat cake made from freshly ground *dal* or millet flour, spiced with chilli, ginger, or onion, deep fried to golden brown colour in peanut oil.

Papad is a crispy salted wafer made with *dal* (many kinds of beans), vegetables, and cereals. This food is a deep-fried circular wafer, thin like paper, and golden yellow (Figure 63b). Those beans are *Cajanus cajan*, *Cicer arietinum*, *Lens culinaris*, *Pisum sativum*, *Vigna mungo*, and *Vigna radiata*.

Murukku is a rice (and *dal* or millet) flour snack in the shape of coil, moulded by hand and fried in oil (Skelton and Rao 1975).

Dosa* and *idli

Dosa is a South Indian thin leavened pancake, made from batter, the basic ingredients of which are ground parboiled rice (*cela*) and husked split black bean (*Phaseolus vulgaris* L.) as shown in Figure 59c and Figure 65. This food is also made from wheat, oat, pulse, and so on (Lal 1974). *Dosa* is stuffed with potato curry or dipped in *sambar* and chutney.

Idli is a leavened poundcake made from the same ingredients as *dosa* (Figure 59f and Figure 65). However, *idli* is a steamed food, while *dosa* is fried. The former has been cooked at least for 40 years ago in South India, as rice consumption increased and *idli katoris* (pressure cooker) became

popular. There are two types of the stone griding mortar for preparing *dosa* and *idli* paste, manual or electromotive. *Idli* is eaten with sambar and chutney.

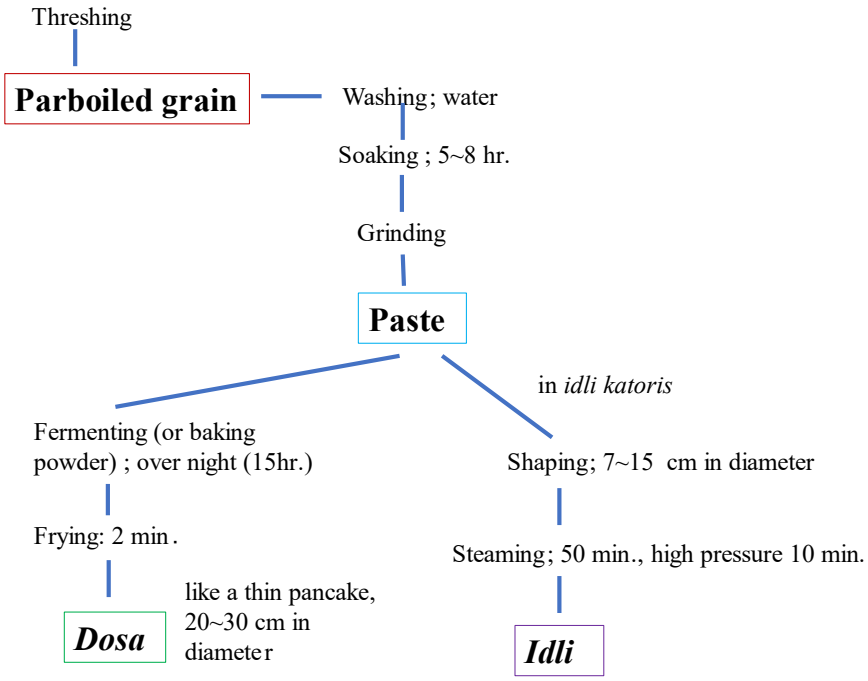


Figure 65. Cooking method of *dosa* and *idli*

Samosa is a deep-fried snack, consisting of a crisp, triangular and layer wheat casing filled with spiced meat or vegetables. In about AD 1300 Amir Khusrau describes, among foods of the Muslim aristocracy in Delhi, the *samosa* prepared from meat, *ghee*, onion, etc (Figure 66a). About fifty years later Ibun Battuta calls it *samusak*, describing it as 'minced meat cooked with almonds, walnuts, pistachios, onions and spices placed inside this envelope of wheat and deep fried in *ghee*' (Achaya 1977).

Figure 66. *Samosa* and Festival foods on banana leaf

There are two main cooking methods of bread, one is unleavened, and another is leavened. *Chapati*, *puri*, *paroatha* and *roti* are unleavened breads, while *nan* and many kinds of breads are leavened breads. These had been originated in Near East, North Africa, India and Europe with the grain crops of Triticeae. Noodles and *baozi* had been made around China via Central Asia to Europe as shown in Figures 67 and 68. There are three cooking methods of noodles, that is, hand-pulled, stretched and extruded.

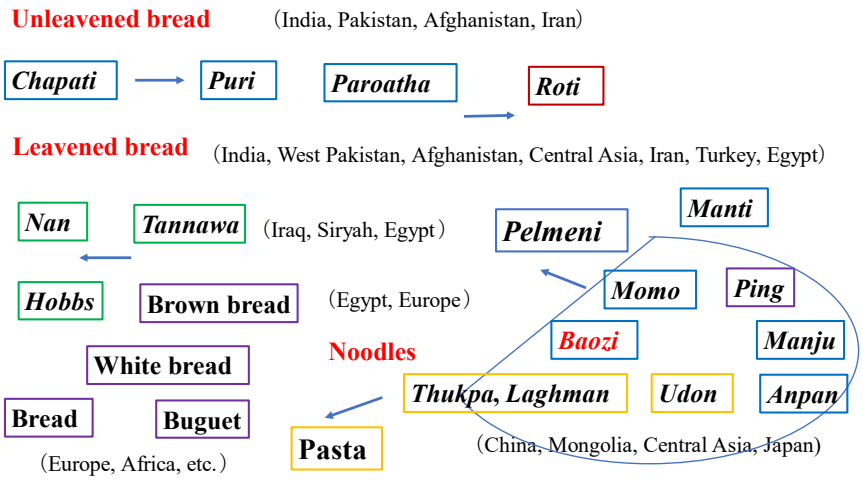


Figure 67. Cooking and Food from wheat flour

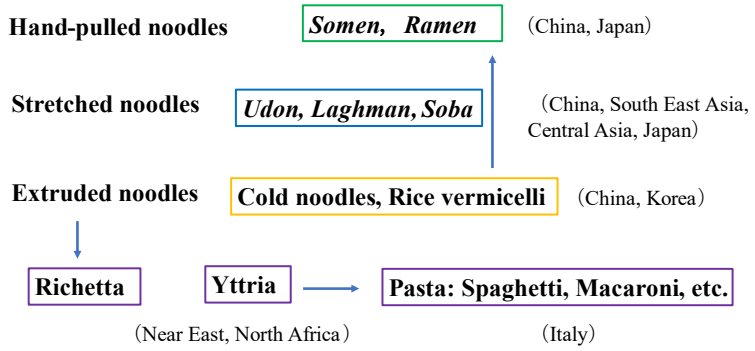


Figure 68. Three cooking methods of Noodles

Mude and *ganji*

Mude (*kali*, *sankati*) is a kind of starch-paste made from millet flour. Mude is homologous to *dhido* in Nepal and *oneri* in Japan. In South India *mude* and *anna* are the most popular ways to cook the staple foods. *Ganji* is a kind of very thin starch-paste made from the same ingredients as *mude* (Figure 69). *Ganji* requires a larger volume of water at boiling than *mude* (Figure 70).

Porridge is made from two millets in South Asia and Europe, and is called *waji* (Halmahhera Islands), *mude* (India), *kochi* (Afghanistan), *mamalyga* (Caucasia), *ugre* (Turkey), *pcheno* (Bulgaria), *māmāliga* (Romania), *polenta* (Italy), *millat* (France), and so on. In some countries dumplings and flour porridge are made from these millets. Dumplings are called *shito* (Ainu people in Hokkaido, Japan), *abai* (Formosa), sweet *ladu* (Pakistan). Flour porridge made from foxtail millet is called *kosayo* (Ainu people), *ganji* (South India), and so on. Bread is mainly made in India and Eastern Europe, and is called *roti* (India), *tathui* (North Pakistan), *kulsik* (Caucasia), *prosenic* (Bulgaria) and so on.

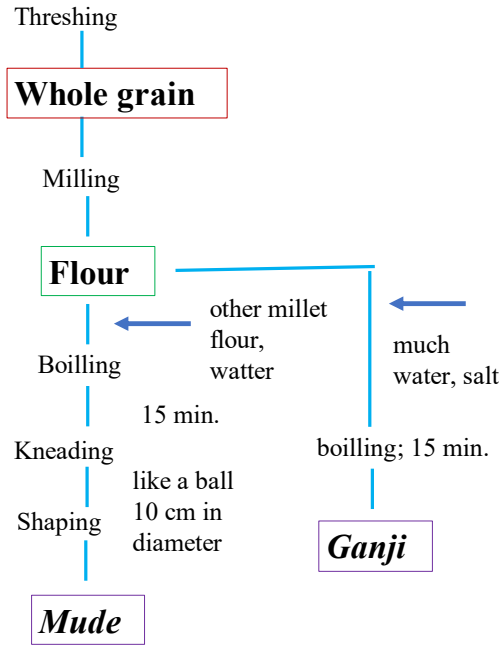


Figure 69. Cooking *mude* and *ganji*

Figure 70. Ganji made from Sorghum and finger millet

Also in Japan, many foods have been made from sorghum as shown in Figure 71. For example, *dango* is made from finger millet in Gunma, *hecchoko-dango/ ukiuki-danngo* are made from sorghum in Iwate, and *mochi* from sorghum in Yamanashi. These millets, finger millet and sorghum had dispersed from Africa, via India and China to Far East Japan together with their same cooking methods. Even now it is an amazing story of the agricultural culture complex.

Figure 71. Many foods made from sorghum in Japan

a, *Dango* made from finger millet in Gunma; b, *Hecchoko-dango* made from sorghum in Iwate; c, *Ukiuki-dango* made from sorghum in Iwate; d, *Mochi* made from sorghum in Yamanashi.

Comparison of cultivation, processing and cooking methods between *korne* and *korati*

The various food preparations made from *korne*, *Brachiaria ramosa* are shown in Figure 42a and 59c. Nine kinds of food can be classified as grain and flour foods. The grain foods include boiled grain (*anna*) and sweetened gruel (*kheer*). The broken grain is used for preparing semi-solid porridge (*nuchina mudda*). There is no practice of parboiling grains. In the Tumkur district, farmers usually eat *anna* twice a month, but *kheer* only on festivities. Flour foods consist of unleavened bread (*roti*), leavened thin pancake (*dosai*) and a few deep-fried snack foods (*nippattu*, *chakkulli*, *haralu*, *kodubale* and *kadabu*). The grain foods are prepared by boiling with water, while the flour foods are prepared by baking or frying with vegetable oil (Kimata, M., E.G. Ashok and A. Seetharam 2000).

The grain foods of *korne* are prepared as follows: 1) *anna*. The polished grain was first washed in water, then put into a pot with hot water and boiled over a strong fire for about 6 min. with occasional stirrings with a spatula; excess water is drained off; and then that grain is again steamed over a weak fire for 3 min. The cooked *anna* is served with *sambar* (a kind of spicy vegetable stew) or yogurt. 2) *kheer*. Grain is boiled with a larger quantity of water until it becomes tender, and is mixed with sugar or jaggery to make it sweet and bring it to the consistency of gruel. Fried groundnut

is used for dressing the *kheer*. *Kheer* is also a good food for nursing mothers. 3) *nuchina mudda*. The broken grains and finger millet flour are mixed in a 1:4 proportion and added to boiling water and cooked for 3 min.; They are well kneaded using a flat wooden stick. This batter is put on a wooden plat, kneaded with an iron spatula, and hand-shaped into a ball.

The preparation of six flour foods are as follows: 1) *roti*. The flour is kneaded with water and mixed with chopped onion. Chopped green chilies, broken groundnut and salt are added to taste. This thick dough is shaped into a flat round pancake by hand or rolling pin, and then baked with a spoonful of oil in a frying pan (*hanch*) on both sides. 2) *dosai*. Flour is mixed with water to form a thin batter which is spread on a frying pan and baked with a spoonful of vegetable oil for about 4 min. The baking process for *dosai* and *roti* are more or less the same. *Dosai* is normally served with a side dish of chutney (made of grated coconut and spices) and *sambar*. 3) *nippattu*, *kodubale* and *chakulli*. These are deep-fried snack foods prepared by mixing flour of *korne* with black gram flour or maida (specific fraction of wheat flour) in various proportions. Fried Bengal gram and groundnut are mixed while preparing the dough for *nippattu*. 4) *kadabu*. Flour of *korne* is made by mixing with water. A small quantity of this dough is taken and flattened using a rolling pin and then stuffed with sweet ingredients, and deep-fried in groundnut oil until golden brown.

The grains of *korati*, *Setaria pumila* (syn. *S. glauca*) are used in many food preparations, boiled grain (*anna*), unleavened bread (*roti*), porridge (*sankati*) and thin gruel (*ganji* or *peja*) in South India. *Korati* grains are cooked together with little millet in all these. The parboiled *korati* was observed only once during the survey in Orissa state. At Jalaripalli village, surveyed in 1997, six kinds of food were made.

The grain foods of *korati* were prepared as follows: 1) *annamu*. The process is almost the same as *anna* made from *korne* in Karnataka. 2) *sankati*. Cooked *annamu* is kneaded by wooden sticks and then shaped into ball. 3) *ganji*. Cooked *annamu* is added to boiling water, a little salt and pepper, and mixed. 4) *uppitu*. The broken grains are first washed in water, vegetables such as chili and onion are fried with coriander, mustard seed, chili powder and salt in vegetable oil; fried vegetables are boiled adding water and the broken grains. 5) *kheer*. Broken grains are boiled with large quantities of water until tender, excess water is drained, and that grain is mixed with sugar.

Roti is the only flour food made from the mixed ingredient. The process is the same as *roti* made from *korune*. Both *sankati* made from *korati*, and *nuchina mudda* made from *korne* are modified grain foods, but the *mude* made from the other cereals are usually made from flour and are thus generally classified as flour foods. Apparently, these grain foods are new variations that have appeared in rather recent times.

History on processing and cooking methods of cereals

The porridge was very simple processing/cooking methods in ancient times. Coarse ground porridge and roasted grains of barley/wheat had been one of the oldest foods as shown in Figure 73. Also, roasted ground porridge had been an ancient cooking method in Near East area. Moreover, many methods of flour porridge methods are shown in Figure 74.

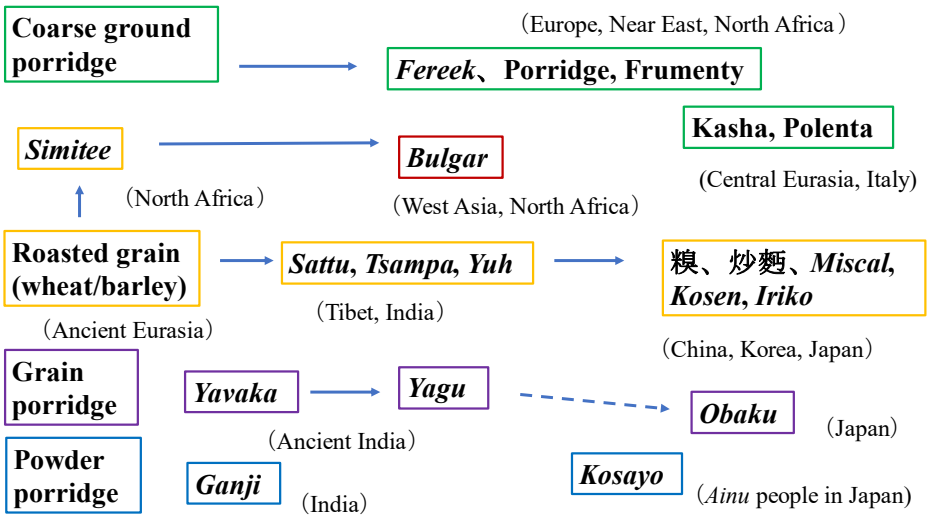


Figure 72. Many kinds of porridge cooking methods

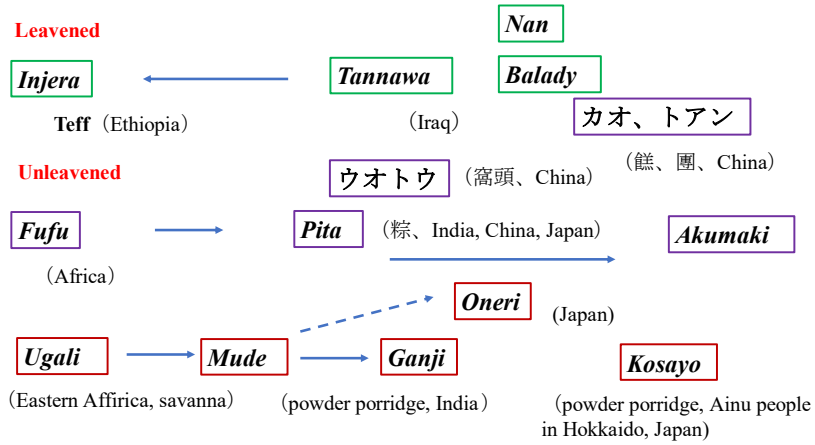


Figure 73. History on flour foods

Fermented drinks and foods

Sherpa people say that *kodo chan* has the best taste of all (finger millet, rice, wheat, barley, and maize) in Nepal. *Kodo* is finger millet in Nepal, but it is not *kodora* (*Paspalum scrobiculatum*). They obtain fermented *chan* (a crude alcoholic drink) or *roksi* (a distilled alcoholic drink) from grain as shown in Figures 75 and 76. Newar people ferment *chan* with the malt of barley, while the Sherpas do so with malted buckwheat. In the traditional manner, Serpas suck *kodo chan*, which has been diluted with boiled water, through a bamboo straw (*chapshing*) from a certain kind of vessel (*tongba*). Similarly,

Non-alcoholic drinks are made in Caucasia and Eastern Europe, and are called *buza* (Caucasia), *boza* (Bulgaria), *mied* (Romania) and so on. Alcoholic drinks are made mostly from waxy grain only in East Asia. Before the process of alcoholic fermentation, the cereal grain (starch) including several millets is saccharised by *koji* (*Aspergillus oryzae*) in East Asia and India, while it is done through

malting in Europe and Africa (Nakao 1967). This difference may be related to the following characteristics of grains. The covered grains of Asian millets must be dehusked and then polished before using them, while the naked ones of African millets do not need such processing.

Sorghum bicolor and *Pennisetum glaucum* are mainly used for making *roti*, while *Eleusine coracana* is mostly used for making *mude* and fermented alcoholic drink *chan* (Figure 74 and 75). With respect to fermented foods, a starter is made from *Hordeum vulgare* (Figure 75c, starter; 75d, a jar for fermentation; 75b, alcohol drink, *chan*, made from *Eleusine coracana*; and 75e, yogurt, *dahi*.

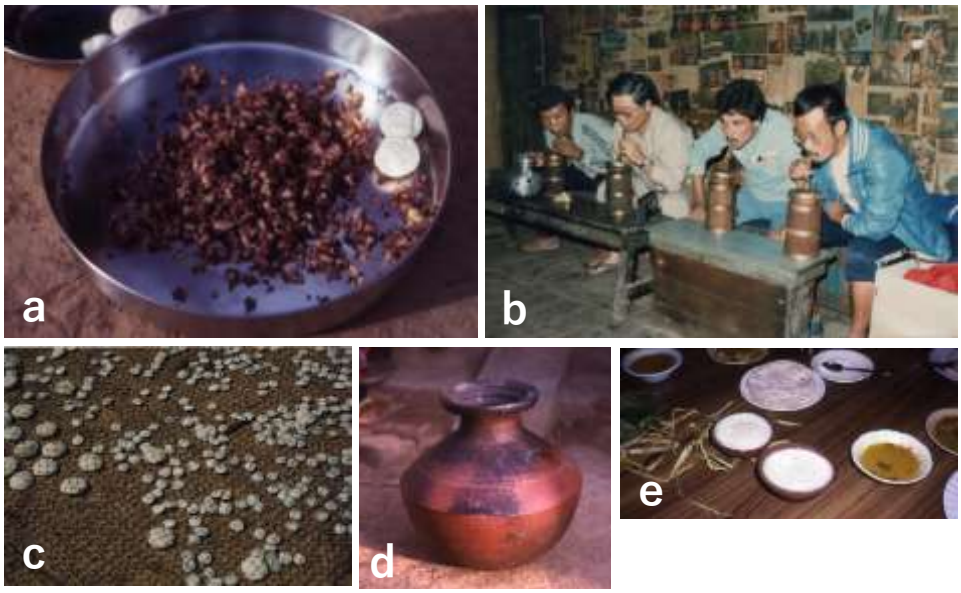


Figure74. Ferment foods

a, yeast made from barley, *Hordeum vulgare*; b, a vessel for fermentation; c, alcoholic drink, *chan* made from finger millet, *Eleusine coracana*; d, yogurt *dahi*.

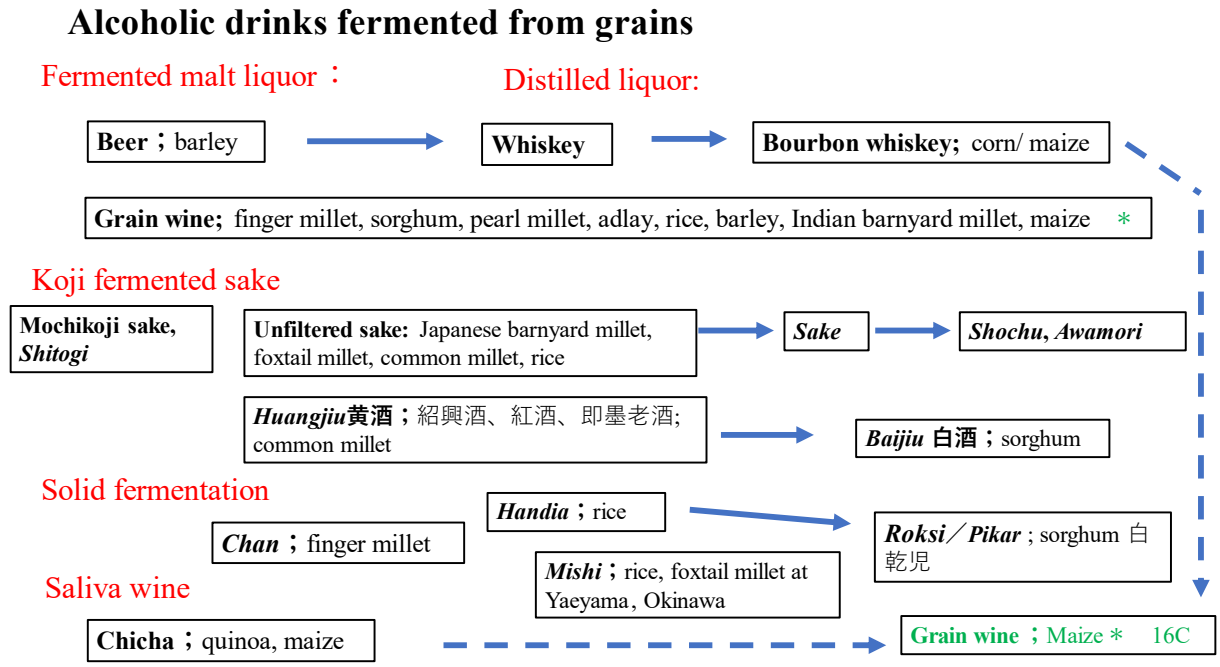


Figure 75. Alcoholic drinks fermented from grains

Food preparation and secondary compounds in grain

The Eurasian foods made from common millet are classified into four processing methods: grain, coarse-ground flour, fine flour, and drinks. Asian people cook boiled grain and porridge from the polished grains of non-glutinous varieties. Especially, East Asians cook steamed grain and *mochi* (a kind of cake) from the polished grains of glutinous varieties and ferment alcoholic drinks from polished grains of both non-glutinous and glutinous varieties. Inner Mongolians drink daily milk tea with roasted grains. Uzbeks top *non* (a kind of bread) with colored grains and cook milk porridge from non-glutinous varieties for lunch at a nursery school. Europeans cook milk porridge from coarse-ground flour, bread from fine flour, and ferment non-alcoholic drinks from polished grains of only non-glutinous varieties. Based on the endosperm starch in seed grains, the varieties were divided into two glutinous or non-glutinous categories. The distribution of glutinous varieties of common millet and *Setaria italica* were restricted to eastern Asia. On the contrary, the geographical distribution of phenol color reaction to seed coats in *S. italica* was very similar to that of *Oryza sativa*, but the distribution in common millet was different from the trends in *S. italica* and *O. sativa* (Sakamoto 1982, Kawase and Sakamoto 1982, Kimata and Negishi 2002).

The four types of local varieties of common millet were categorized by the composition of the minor fatty acids arachidic, behenic, and eicosapentaenoic acid. If the ancestral prototype was the weedy AE type containing arachidic and eicosapentaenoic acids, the AB type (arachidic and behenic acid) may have been bred both in Europe and Asia, while the ABE (all three fatty acids) and O (no fatty acids) types may have originated around Central Asia and then spread to both Europe and Asia (Kimata et al. 2007).

Cereals with waxy endosperm are used to make staple foods not only in Japan, but also in various other countries of East Asia. Waxy endosperm is found in common millet, foxtail millet, Job's tear (adlay), sorghum, rice, barley and maize. From all the information obtained concerning these seven

cereals that have waxy endosperm varieties, the following conclusion can be drawn. The waxy varieties of foxtail millet (Figure 76), sorghum, adlay, rice and maize are distributed over wide areas of East Asia from the mountainous regions of Assam to Japan. The waxy forms of common millet and barley are confined to China, Korea and Japan. On the other hand, they are never found in the western half of Eurasia, the areas ranging from India to Europe, Africa and the New World (Sakamoto 1982).

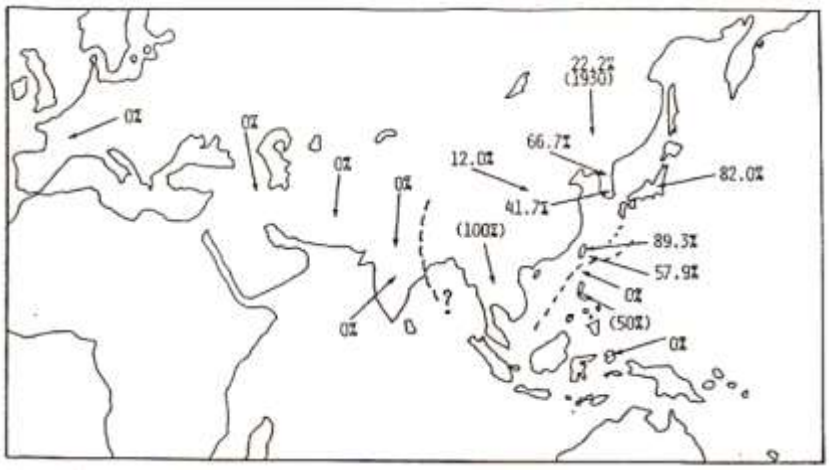


Figure 76. Geographical distribution of the waxy landraces of foxtail millet.
Each rate (%) shows the percentage of waxy landraces in respective region (Sakamoto 1982)

The millets grown in Eurasia have been classified into four groups according to geographical origin. These were dispersed from a certain domesticated region throughout the Eurasian land mass during pre-historic ages. The processing and cooking of millets is the most important parts of basic agricultural culture complex. Therefore, a comparative study on processing and cooking methods must help to clarify the geographical origin and dispersal of a given millet (Kimata 1987, 1989). The processing and cooking methods used for the following four groups of millets are compared in order to study the relationship between processing and cooking methods and dispersal of millets into South and East Asia.

Common millet and foxtail millet (Group I)

Since ancient times many traditional foods and drinks have been made from common millet and foxtail millet extensively in wide area of Eurasia. The preparation oof boiled grain, gruel, *mochi* and alcoholic drinks is popular in East Asia, while meal porridge, bread and non-alcoholic drinks prevail in Southeast Asia and Europe as shown in Table 43 (Sakamoto 1987a, partly modified). Boiled grain is made from waxy and non-waxy grain, but the former grain is supplementally used for the latter. It is called *meshi* (Japan), *anna* (India), *gharaji* (Pakistan) (Kawase and Sakamoto 1989) and so on. Gruel is made only non-waxy grain in East Asia, while *mochi* is make only from waxy grain.

Table 43. Foods and drinks made from the grains of common millet and foxtail millet in Eurasia

Region	Types of cooking								
	Grain			Meal	Flour			Drink	
	Boiled grain	Gruel	Mochi	Porridge	Dumpling (dango)	Flour porridge	Bread	Non-alcoholic	Alcohlic
Japan									
non-waxy	○	○			△				
waxy	○		○		○	△		○	○
Korea									
non-waxy	○								
waxy	○		○						○
China									
non-waxy	○	○					○		○
waxy			○				○		○
Formosa									
non-waxy	○								
waxy	○		○		○				○
Batan Island				○					
Halmahera Islands				○					
India	○			○		○	○		
Pakistan	○				△		○		
Afghanistan				○			○		
Caucasia				○					○
Turkey				○					
Bulgaria				○			○		○
Romania				○					○
Italy				○					
France				○					

(Sakamoto 1987a modified)

Indian millets (Group IIa)

Indian cookery has enriched over a period of many centuries by different cultures that were super-imposed with each new wave of invaders. These invaders introduced new cooking ingredients and techniques that late spread to different regions of the Indian subcontinent, but mostly enhancing and refining the North, where the new hordes primarily settled because of the similarity of climate and landscape to those that they came from. Furthermore, natural barriers and great distances made migration to the South slow and infrequent (Sahni 1986).

Many cereals accompanied each cooking method introduced many times from several regions into Deccan Plateau. *Chawal* (boiled grain) made from Asian millets (Group I and IIa) and rice is often made in Eastern India, while *roti* (bread) made from millets (mainly Group IV) and *Chapati* (unleavened bread) made from wheat that are modified from Mediterranean flour food frequently made in Western India as shown in Table 44 (Kimata 1987).

Mude modified from African meal porridge (mainly Group IV) is often cooked from many kinds of cereals restricted to South India and Nepal (also In Japan), but not in North-Western and Central India. Generally speaking, the characteristics of Indian cookery are divided into two main parts, i.e., the North and the South, delineated by a line writing from Bombay (Mumbai) to Hyderabad. *Mude*, *ganji* (flour porridge), *dosa* (thin leavened pancake) and *idli* (leavened poundcake) are also frequently cooked only in South India. The diversity of cooking styles is the most remarkable in Tamil Nadu. Going toward the West, there is a decrease in the variety in the cooking styles and the farmers mainly eat *chapati* and *roti*. However, going toward the East while the same tendency occurred farmers eat mainly *chawal*.

Table 44. Cereal cooking styles and their ingredients in India

Grope	Cooking												Total
Ingredients	*Chawal*	*Upuma*	*Chapati*	*Roti*	*Non*	*Puri*	*Wada*	*Dosa*	*Idli*	*Mude*	*Ganji*	*Mavu*	
I													
Pan. miliaceum	○	△		○			△			○	○		6
Se. italica	○	△		△			○	○		○	○	○	8
II a													
B. ramosa	○		○	○						○			3
Ec. frumentacea	○	△					○			○	○		5
Pan sumatrense	○	○		△			○	○		○	○		7
Pas. scrobiculatum	○			○						○	○		4
Se. pumila	○			△						△	△		4
IV													
El. coracana	△	○		○			○	○	○	○	○		8
Pe. americanum	○	○		○						○	○		5
So. bicolor	○	○		○			○	○	○	○	○		8
O. sative	○	○					○	○	○	○	○	○	8
H. vulgare		○		○				○	○	○	○		6
T. aestivum			○		○	○		○		○	○		6
T. dicoccum		○							△				2
T. duram		△	△			○			△				4
Z. mays	△	○		○			△			△	○		6
Total	12	12	2	11	1	2	8	7	6	14	13	2	90

The grain of adlay **(Group IIb)** is ground into flour and is either used to make bread or a sweet dish is prepared by frying the grain and adding sugar. The whole grain is also eaten raw as a snack, or fermented to produce beer in Assam (de Wet 1989). Adlay is also used to make *prisan* (a non-alcoholic drink) in Korea and Japan, meal porridge in Formosa and Halmahera Islands, and *mochi* in Korea and Formosa.

Japanese barnyard millet (**Group III)** is used to many kinds of foods in Japan i.e., boiled grain (*meshi*), gruel (*kayu*), *hie-mochi* (made from non-waxy grains), meal porridge (*oneri*), dumplings (*dango*), flour porridge, and alcoholic drinks (*doburoku*). In Cheju Island, Korea, this millet may be used to make boiled grain.

African millets (Group IV)

In Afro-Eurasia various foods and drinks have been made from the grains of African millets as shown in Table 45 (Esele 1989; Jiaju 1989: Kimata 1983, 1987, 1989; Malleshi 1989; Rao *et al*. 1985; Sakamoto and Fukui 1972; Sakamoto *et al.* 1980; Shigeta 1987; Takei 1984). Boiled grain is mostly made from sorghum in South-East Asia, and is called *meshi* (Japan), *chawal*, *anna*, *bhat*, *sadam* etc. (Indian subcontinent). It is traditionally made by the "drying up" method in East Asia, while it is done by "draining off," hot water removal method in Indian subcontinent. Gruel (grain) is not made from any African millet. *Mochi* (a kind oof cake made from grains with waxy endosperm) is made from sorghum in Japan and Korea, and is called *mochi* and *docok*, respectively. Meal porridge is made from finger millet, sorghum and pearl millet in East Asia, India, and Africa, and is called *oneri* (Japan), *dhido* (Nepal), *mude*, *kali*, *sankati*, *onda*, etc. (India), *ugari* (Uganda), *kwon* (Sudan), *tō* (Ghana) and so on. This meal porridge has been a very important staple food in Africa and India. The dumpling (*dango*) is only made from finger millet and sorghum in Japan. Flour porridge is made from all three African millets, and is called *ganji*, *kulu* (India), *nyoka* (Sudan), *koko* (Ghana). Bread (*roti*) is made from African millets only in the Indian subcontinent. Non-alcoholic

drinks are made from only finger millet in India and Uganda. Alcoholic drinks are fermented from all three millets mostly in the Indian subcontinent and Africa, and is called *chan* and its distilled *roksi* (Nepal), *handia* (Bihar, India), *talla* and its distilled *araki* (Ethiopia), *kongo* (Sudan), *pito* (Ghana) and so on.

Table 45. Foods and drinks made from the grains of finger millet, sorghum and pearl millet in Afro-Eurasia

Crops/Region	Type of cooking								
	Grain			Meal	Flour			Drink	
	Boiled grain	Gruel	*Mochi*	Porridge	Dumpling (dango)	Flour Porridge	Bread	Non-alcoholic	Alcoholic
El. coracana									
Japan			△	○	○	△	○		
Nepal				○			○	○	○
India	△			○		○			○
Sudan				○					○
Ethiopia								○	○
Uganda				○		○			○
Burkina Faso				○					
So. bicolor									
Japan	△		○		○				
Korea	○		○						○
China									○
Halmahera	○								
India	○			○		○	○		
Sudan				○		○	△		○
Ethiopia									○
Burkina Faso				○					○
Pe. americanum									
India	○			○		○	○		
Sudan				○					△
Ghana				○		○			○
Burkina Faso				○					

Cooking method and foods made of millets

The Indian subcontinent is a wonderland for studying the domestication process of grain crops. Several species of millet are domesticated in this region. Cooking of cereals forms an important part of the basic agricultural culture complex. This culture complex is composed of their vernacular names, religious function, archaeological evidence, etc. In the next chapter 7, I will explicate those data. I had participated six times in expeditions for millet research and collected numerous accessions of millets and their relative species, with information on their agricultural complex, from hundreds of farmers in their villages and fields.

Ancient farmers had originally domesticated six species of millet from the relative weed species in India. Indian millet species were domesticated in the process of diffusion from humid paddy fields in Eastern India to dry upland rice fields in the Deccan Plateau, Southern India.

Indian food culture has been a reflection of the people's heritage. It represents India's historical development, religious beliefs, cultural practices, and above all, geographical attributes (Sahni 1986). In the Indian subcontinent, staple foods made using grain crops are served with various types of spicy curries and legume *dal* stews (*dhal*). Many unique cooking styles can be found for each cereal in any part of the subcontinent (Aziz 1983, Sahni 1986). Cooking of cereals forms an

important part of the agricultural complex (Maeshwari 1987, Sakamoto 1988). Indian cooking consists of a unique combination of special cooking styles developed for each grain crop (Kimata et al. 2000). Moreover, the agricultural complex is composed of their vernacular names, religious function, archaeological evidence, etc.

It is very interesting to look for some basic elements of the Indian cooking of those cereals which might be found in Japanese methods for cooking grains. Therefore, a comparative study of the methodology of cooking is one of the scientific approaches which can help clarify the geographical origin and dispersal of given grain crops.

People have cooked many types of food using millets and cereals. Mainly *bhat* (*meshi* in Japanese), *roti* (*pan*), and *mude* (*oneri*) are cooked because they are frequently made using most of the cereals listed in Table 3 (Kimata 1987). *Bhat* is the most popular food, a boiled grain food made using all the ingredients shown in Fig. 4a, 4d right, and 5a (2nd from upper right). *Bhat* originated in ancient China and was brought to the Indian subcontinent via Eastern India. *Roti* is also a popular food made from cereal flour and originated from the cooking of wheat bread in the Fertile Crescent and was brought to the subcontinent via Western India.

People have cooked many types of food using millets and cereals. Mainly *bhat* (*meshi* in Japanese), *roti, mude* (*oneri*) are cooked because they are frequently made using most of the cereals listed in Table 46 (Kimata 1987). *Bhat* is the most popular food, a boiled grain food made using all the ingredients previously mentioned. *Bhat* originated in ancient China and brought to the Indian subcontinent via Eastern India. *Roti* is also a popular food made from cereal flour and originated from the cooking of wheat bread in Fertile Crescent and was brought to the subcontinent via Western India. *Mude* is a popular food made from cereal flour and originated from the cooking of *ugari* brought from Eastern Africa via the Arabian Peninsula. Figures 78 and 79 show cooking methods for cereals in Indian subcontinent: (a) a traditional boiled rice with *papad*. *Papad* is crispy salted wafer made from *dal*, vegetables, and cereals. (b) *upma* and *kesari bhat*. (c) *dosa*. (d) *mude* and boiled grain made using *Brachiaria ramosa*. (e) *puri* and (f) *idli*.

Sorghum bicolor and *Pennisetum glaucum* are mainly used for making *roti*, while *Eleusine coracana* is mostly used for making *mude* and fermented alcoholic drink *chan*. Other millet species are mainly used for *bhat*. A special food *mavu*, is made from the raw flour of *Setaria italica* and *Oriza sativa* as offering for gods and goddesses during festivals. Nine foods are made using *Brachiaria ramosa*, *mude* is made using *Eleusine coracana*, and *chapati* is made using wheat, *Triticum aestivum*. With respect to fermented foods, a starrer is made from *Hordeum vulgare*.

Our cookeries are shown in Tables 46 and 47. *Upma* is a coarse-grain food. *Dosa* is a thin leavened pancake, and moreover, *masara dosa* is stuffed with potato curry. Idli is a leavened pound cake made using the same ingredients as *dosa*. *Vada* is a cake made from freshly dal or millet flour. *Ganji* is a very thin starch-paste made from the same ingredients as *mude*.

Table 46. Millets and their food in the Indian subcontinent

Species name	Food								
Indian name	bhat	upuma	roti	vada	dosa	idoli	mudde	ganji	mave
Japanese name	meshi		pan	age pan		mushipan	oneri	konagayu	shitogi
Sorghum bicolor	○	○	◎	○	△	○	○	○	
Pennisetum americanum	○	○	◎				○	○	
Eleusine coracana	△	○	○	○	○	○	◎	○	
Setaria italica	◎	△	△	○	○		○	○	○
Panicum miliaceum	◎	△	○	△			○	○	
Panicum sumatrense	◎	○	△	○	○		○	○	
Paspalum scrobiculatum	◎		○				○	○	
Echinochloa flumentacea	◎	△		○			○	○	
Brachiaria ramosa	◎		○	○			○	○	
Setaria pumila	◎		△				△	△	
Digitaria crusiata	◎		○						

◎, main ingradient used; ○, generally; △, rarely or suppliment mixed.

The number of ingredients on each cooking styles in South -East India

The number of ingredients made main 12 foods are shown in Table 47. *Chawal* (*bhat*,48) and *roti* (42) are made frequently by the most ingredients. *Ganji* (36) is cooked by many ingredients in Tamil Nadu and Mahdia Pradesh, *Mude* (*Mudde*, 27) is cooked by many ingredients in South India. *Upma* (26) is many in Karnataka and Tamil Nadu. *Chapati*, *nan* and *puri* made from wheat flour are cooked around West India. *Vada* is cooked mainly in Tamil Nadu, *dosa* is cooked in South India, and *idli* is cooked in Karnataka. *Mavu* is made only in Tamil Nadu. Decreasing with the distance from Tamil Nadu to the north, the number of ingredients is clearly decreased, namely the diversity of cooking styles in millets is declined.

Table 47. The number of ingredients on each cooking styles in South -East India

Cooking style	Number of ingredients							Total
	Maharashtra	Mdhya Pradesh	Karnataka	Tamil Nadu	Andhra Pradesh	Orissa	Bihar	
Chawal	3	8	6	9	8	7	7	48
upma	0	0	9	11	2	3	1	26
chapati	1	1	1	2	1	1	1	8
roti	4	10	7	4	6	2	9	42
nan	1	0	1	0	0	0	0	2
puri	1	0	1	1	1	1	0	5
vada	1	0	1	8	0	0	0	10
dosa	0	0	4	7	5	1	1	18
idli	1	0	4	1	1	1	1	9
mude	0	0	7	12	7	1	0	27
ganji	2	10	3	11	5	5	0	36
mavu	0	0	0	2	0	0	0	2
Total	14	29	44	68	36	22	20	233

On the other hand, cereals and the number of their ingredients cooked in the Deccan Plateau are shown in Table 48. For cooking main 12 foods of cereals, rice (34) is used most frequently, and followed by *samai* (25), foxtail millet (25) and *ragi* (finger millet, 23). The other cereals are used for cooking foods around Indian subcontinent. However, barley, emma and durum wheat are only grown at mountainous villages. *Korati* (8) and *korne* (4) are grown only at the confined area in Eastern Decan. The methods of processing/cooking are summarized in Figures 77 and 78.

Table 48. Cereals and the number of their ingredients cooked in the Deccan Plateau

Ingredients	Number of ingredients							Total
	Maharashtra	Mdhya Pradesh	Karnataka	Tamil Nadu	Andhra Pradesh	Orissa	Bihar	
El. coracana	1	1	6	7	4	3	1	23
Pe. americanum	1	1	2	4	2	1	2	13
So. bicolor	0	2	4	7	3	0	1	17
H. vulgare	0	2	0	5	0	0	0	7
T. aestivum	3	3	3	4	2	2	1	18
T. dicocum	0	0	0	1	0	0	0	1
T. durum	0	0	2	3	3	0	0	8
P. miliaceum	0	0	4	5	1	0	2	12
S. italica	1	2	5	7	5	3	2	25
O. sativa	5	3	6	7	5	4	4	34
B. ramosa	0	0	3	0	0	1	0	4
Ech. frumentacea	0	3	0	5	2	2	1	13
P. sumatrense	3	3	5	6	4	2	2	25
Pas. scrobiculatum	0	3	2	3	1	2	2	13
S. pumila	0	3	0	0	4	1	0	8
Z. mays	0	3	2	4	0	1	2	12
Total	14	29	44	68	36	22	20	233

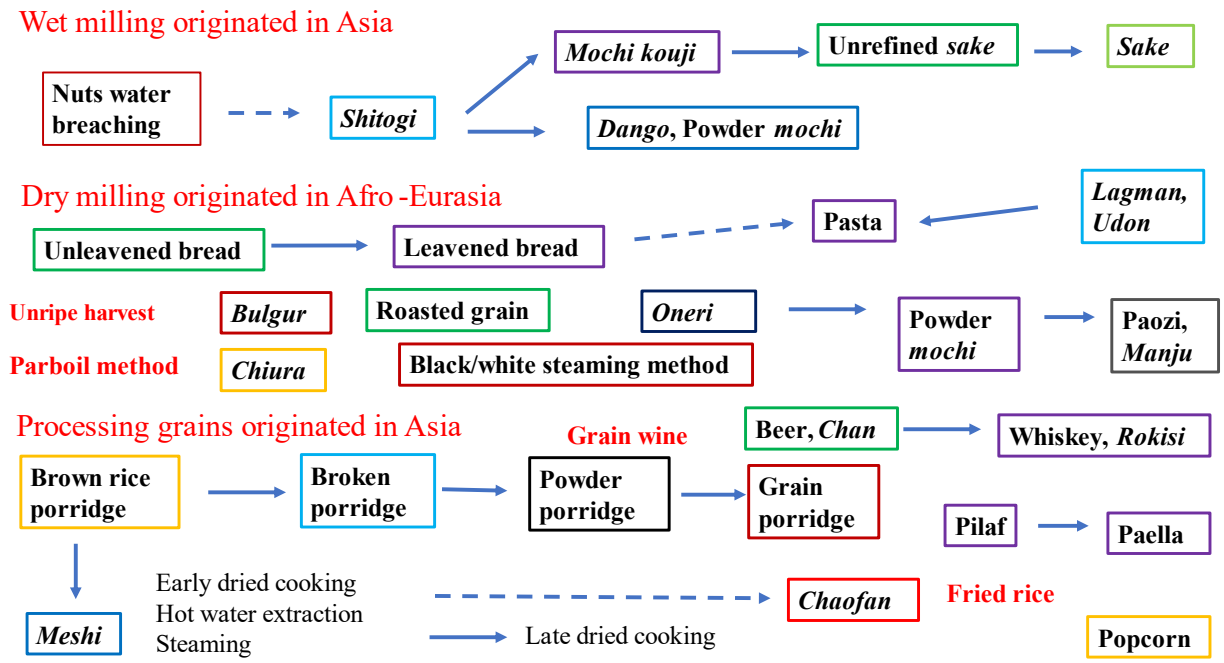


Figure 77. Milling, processing, and then cooking cereal grains

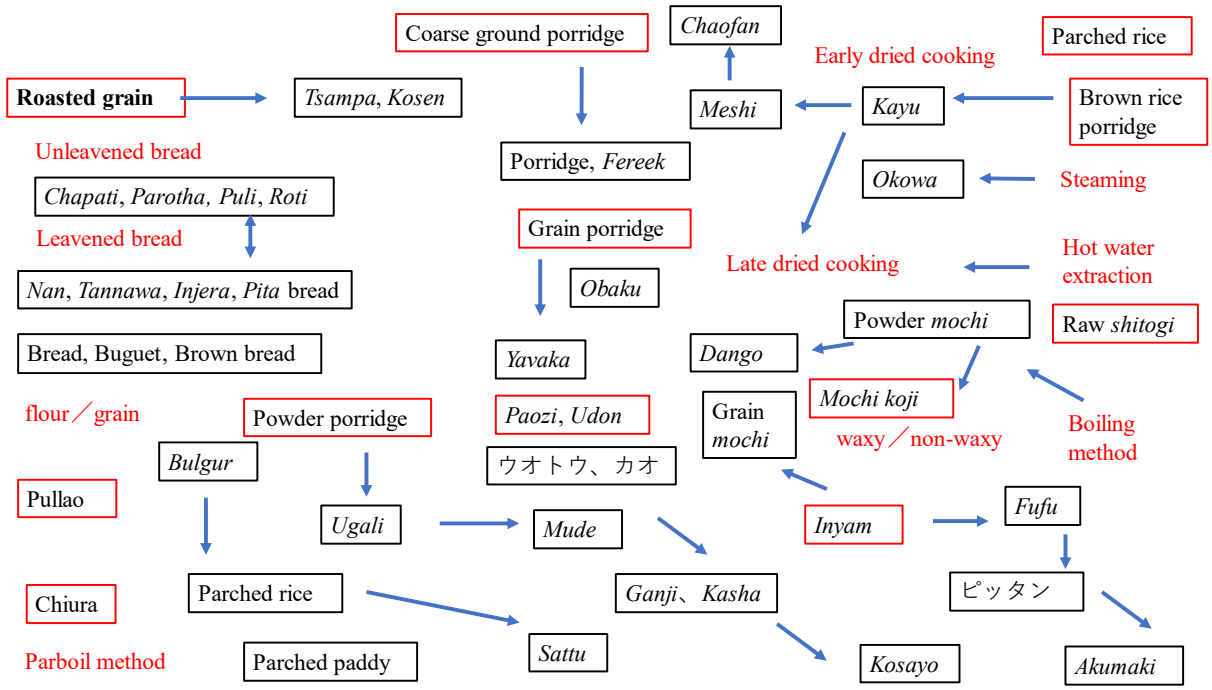


Figure 78. Historical relationship diagram of processing and cooking grain

Cereal seed grains are not easy to process for cooking, but these grains are able to storage for a long time. Therefore, they had been used to stable foods, and also a national tax. Many cereals accompanied each cooking method introduced many times from several regions into the Decan Plateau. The biocultural diversity of cereals, especially of millets, has guaranteed our security of daily life, because it has become rich historically by the acceptance into and transformation in Indian subcontinent.

Chawal (syn. *bhat*, boiled grain) made from Asian millets and rice is often made in Eastern India, while *roti* (bread) made from millets and *chapati* (unleavened bread) made from wheat that are modified from Mediterranean flour food are frequently made in Western India (Kimata 1987). Mude modified from African flour porridge is often cooked from many kinds of cereals restricted to South India and Nepal (also in Japan), but not in North-Western and Central India. Generally speaking, the characteristics of Indian cookery are divided into two main parts, i.e., the North and the South, delineated by aa line writing from Mumbai (Bombay) to Hyderabad. *Mude*, *ganji* (flour porridge), *dosa* (thin leavened pancake) and *idli* (leavened poundcake) are also frequently cooked only in South India. The diversity of cooking styles is the most remarkable in Tamil Nadu. Cooking toward the West, there is a decrease in the variety of cooking styles and the farmers mainly eat *chapati* and *roti*. However, going toward the East while the same tendency occurs farmers eat mainly *chawal*.

The integrating hypothesis for the dispersal route of Indian millets is illustrated in Figure 79 on the basis of the results. *Echinochloa furumentacea*, *Panicum sumatrense* and *Paspalum scurobiculatum* were secondary crops to upland rice. First, their ancestral plants were companion weed derived from the relative weeds that invaded paddy fields in humid regions of Eastern India. Second, the companion weeds became insurance crops in upland rice fields, and they spread to a dry region in Deccan Plateau (Kobayashi 1987, 1989). *Brachiaria ramose* and *Setaria pumila* were so called tertiary crops to the other millet species domesticated from their relative weeds in upland

fields. On the other hand, *Digitaria cruciata* has been recently derived from the relative weed grown in maize or vegetable fields, Kashi Hill, Megaraya, and is limited to the same area (Singh and Arora 1972).

Tentatively, Indian millet species were domesticated in the process of diffusion from humid paddy fields in Eastern India to dry upland rice fields in the Deccan Plateau, Southern India. The domesticated place of rice was Pearl River, rice had been dispersed from South China, via Zomia to East India.

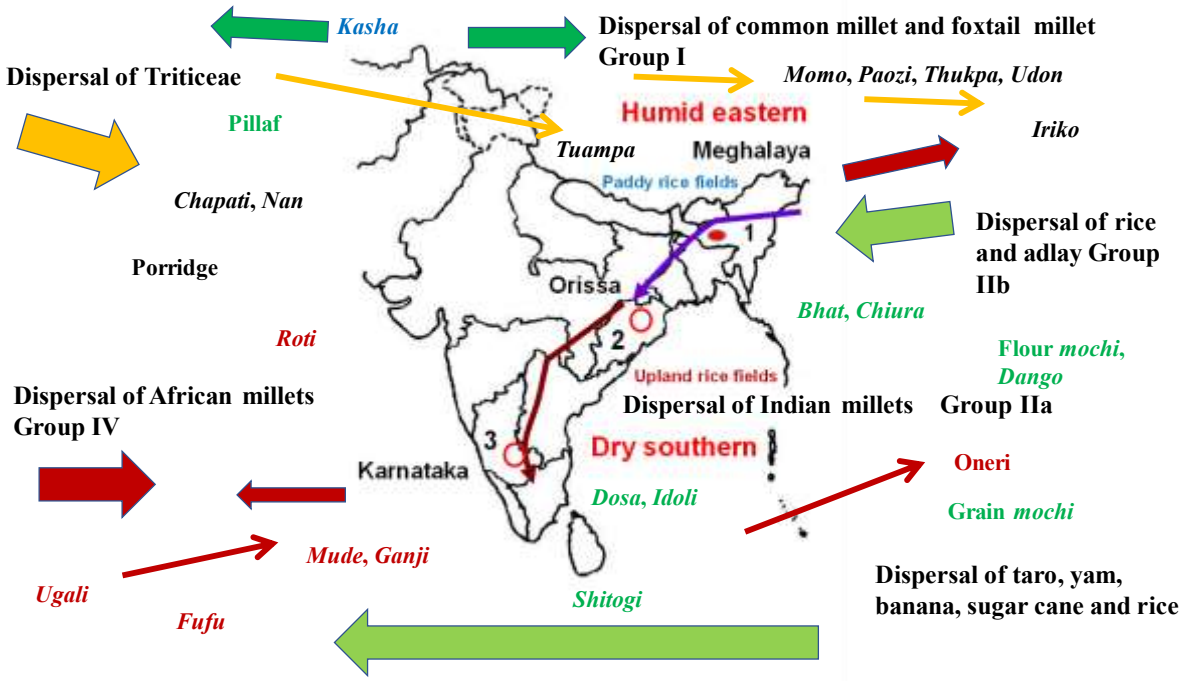


Figure 79. Dispersal of crops in the Indian subcontinent

Up-to-date utilization of millet in Japan

In the Far East (Japan), the following six millets have traditionally been grown and used; common millet, foxtail millet, adlay, Japanese barnyard millet, finger millet and sorghum. Japanese cooking has developed under the influence of Africa, India, and Chinese agricultural complexes. It is very interesting to look for some of the basic traditional elements of such cooking of millets that might be found in Japanese methods for cooking grains. For example, as mentioned above, Indian *mude* is mainly made from African millets, and is homologous to Africa *ugari*. A similar food is called *dhido* in Nepal and *oneri* in Japan. That is to say that the cooking of ugari has spread from Africa to the Far East using various millets, including Asian millets, maize and buckwheat (*Fagopyrum esculentum* Moench.).

Today, Japanese staple foods are mainly a boiled grain made from rice or a bread made from wheat flour. The above-mentioned six millets are now rarely cultivated except in a few mountain villages. Recently, however, Asian millets, common millet, foxtail millet and Japanese barnyard millet have been used to prepare efficacious foods against atopic dermatitis, an allergic disease, for the many Japanese children who are very sensitive to other staple foods such as rice and wheat. Many kinds of foods (for example, breads, cookies and noodles) are attempted to be prepared using

several kinds of millet. Millet derived foods are also efficacious for arterial sclerosis, colon cancer, and anemia because millet has more dietary fibre and iron ions than rice. Dietary fibre reduces the cholesterin content in blood and sustains good conditions for bacterial flora in the colon. The iron ion promotes erythropoiesis.

Millets are very important crops in semi-arid and mountainous regions, and must therefore be maintained, in association with traditional cooking, religious celebrations, as important materials for future utilization. Millet should attain more important position as food grain and fodder in the near future, because of desertification and population increase. No doubt most important utilization of small millets is for food; but these crops are used for various other purposes. Their leaves and culms are nutritious fodder for cattle. The millet cultivation maintains the sustainable agriculture together with the livestock farming. The small grains of millets also form feed for pet birds. This utility cannot be ignored because of the large demand in European countries and Japan.

While the traditional foods need to be handed down, the modern foods must be developed, the modern foods must be developed. A perspective plan for millets utilization should be drawn through interdisciplinary, institutional industry collaboration and as well as international cooperation.

Chapter 7: A New Model of Millet Dispersal Hypothesis

The excellent hypothesis on the origins of domesticated plants and the four agricultural complexes had been derived me to the studies on domestication process of millets (Nakao 1966, 1972; Sakamoto 1988, Sasaki 1994). However, I think that it must be collected a little as described in this chapter 7 today. In the first instance, it is the most important reason that the domesticated place of rice was become clear. The place was changed Bihar, Eastern India to Pearl River, Southern China (Huang, Kurata et al. 2012). The oldest rice grains had been excavated at Shangshan, Pujiang, China, and the domestication of rice had been begun around 11,000 BP (Xinhua News 2020).

Nakao's hypothesis

Nakao's hypothesis was able to summarize the following eight points.

1. The features of the cultural complex on Root Cultivation Farming

1) Farming without seeds

2) Progress in using polyploidy species

3) Lack of beans and oil crops

4) Spot sowing with digging stick

5) To a swidden from a back garden

6) Using Job's tear

7) Dispersal of Root Cultivation Farming to Africa

2. Finger millet was a basic essential element of the cultural complex on Savanna Farming. Common millet and foxtail millet had been domesticated in the dry area from North West India to West Pakistan. Korati (*Setaria glauca*, syn. *S. pumila*) in Bombay state (Today Maharashtra and Gujarat). The original place of domesticated genus *Setaria* had been in the Indian subcontinent. The genus *Echinochloa* had been domesticated *E. frumentacea* in the Indian subcontinent and another species in the temperate zone of evergreen broadleaf forest, then dispersed to Japan.

3) It was completely different between the characteristics of domesticated species and weeds, while these were totally competitive relationship. The secondary crops had not been domesticated in the Savanna farming complex, because farmers had practiced drilling millet seeds and careful weeding. On the contrary, the weedy species of tribe Triticeae were not adversaries, the many secondary crops had been domesticated from their relative weeds

4) Savanna farming complex had started gathering wild grains for foods during monsoon season. In the heavy rain area, there were the large populations of Poaceae plants which had grown in wetland. Human being had selected a wild rice, one of millet, and they had domesticated it growing in such new habitat as paddy fields. Because rice was not special crop among millets, there were not the rice cultural complex. It was included in the savanna farming complex, which had been influenced by the root farming complex.

5) The rice had been started on growing as a kind of millet in the Indian subcontinent. Rice had been

specially grown at the paddy fields, where were at the plains. Then the new varieties of upland rice were differentiated at the mountainous area of East Assam after its dispersal to the east.

6) Rice is transplanted in the same way as finger millet. Finger millet takes root very well even on the upland field, because it is transplanted in July during the rainy season of Monsoon. Rice transplanting might have imitated the practice of finger millet. It had been a possibility that the practice had begun in Bihar, the Indian subcontinent.

7) The mountain area in Assam was a zone of Root Farming Complex. The farmers had grown root crops by digging stick. When rice had dispersed here, they had sown an upland field on swidden with rice by the same practice of hill seeding as root crops. The upland rice was in apposition to millet, e.g. foxtail millet and common millet, with the waxy variety of Job's tear. These grain crops were all annual plants.

8) When farmers harvested the immature seed grains, the grains contained a lot of water, and then these were unsuitable for the storage. They had to eat or process them right now. Yakigome (parched rice) were processed as follows; farmers harvested early rice grains (waxy), steamed the grains by a pot, pounded in a mortar, and got flatten rice without the husks. This product was pregelatinized starch rice, had excellent storage properties, and they were able to eat just adding water. Japanese barnyard millet was one of main foods until the Meiji period in Japan. This refining method was called "shiromushi" and "kuromushi" accompanied by seaming, and then polished the grains.

Reconsideration on the origins of main foods based on their history and archaeology

The first occurrence of grain crops in South Asia is summarized in Table 50 which is based on Fuller et al. (2001) but modified with additional information (Fuller and Madella 2001; Fuller, personal communication). *H. vulgare*, *Triticum* species (great many), and *Avena sativa* (a few) were identified in the Early Phase (around 4500 B.C.) of Harappan sites. *O. sativa* (many) and *Panicum miliaceum* (a few) were identified in the Mature Phase (around 2600 B.C.). Then, *Setaria* species (great many), *Sorghum bicolor* (many), and *Pennisetum glaucum* (syn. a*mericanum*, trace) were found in the Late Phase (around 2000 B.C.). The following species were found in early South Indian sites (2300 to 1800 B.C.): *Panicum sumatrense* (trace), *Brachiaria ramosa* (many), *Setaria verticillata* (many), and *Setaria pumila* (trace). Then, traces of *Paspalum scrobiculatum* and many *Echinochloa* cf *colona* (possibly *Echinochloa frumentacea*) were identified in the late sites (1800 to 1200 B.C.). Asian millets occurred historically in the following order: *Panicum miliaceum*; *Setaria* species; then *Brachiaria ramosa*, *Setaria verticillata*, *Panicum sumatrense*, and *Setaria pumila*; and *Echinochloa* cf *colona* and *Paspalum scrobiculatum*. However, *Brachiaria ramosa*, *Setaria verticillata*, *Setaria pumila*, and *Echinochloa* cf *colona* might have been gathered as the wild grains.

Table 50. Summary on the first occurrence of grain crops in South Asia

Species / Period	Early 4500 B.C.–	Mature –2600 B.C.	Late –2000 B.C.	(South India) 2300–1800 B.C.	1800–1200 B.C.	–0 A.D.	1500 A.D.	1900 A.D.
Paspalum scrobiculatum					trace			
Panicum sumatrense				trace	a few			
Echinochloa cf. colona					many			
Brachiaria ramosa			wild?	many	many			
Setaria verticillata			wild?	many	many			
Setaria pumila			wild?	trace	trace			
Setaria sp.			a great many					
Digitaria cruciata								domesticated
Digitaria sanguinalis							(unknown, disapeared)	
Panicum miliaceum		a few						
Panicum sp.			a few					
Setaria italica			possible					
Eleusine coracana			?	possible				
Sorghum bicolor			many					
Pennisetum glaucum			trace	trace	trace			
Coix lacryma-jobi						possible		
Oriza sativa		many		trace	trace			
Hordeum vulgare	a great many			many	many			
Triticum dicoccum				trace	trace			
Triticum durum/aestivum				many	trace			
Triticum sp.	a great many			many	many			
Avena sativa	a few							
Zea mays							introduced	

Modified and Based on Fuller et al. 2001, Fuller and Madella 2001, and Fuller (personal communication).

The vernacular names of Indian cookery-used cereals are shown in Table 32. The various millets were cultivated and used for a lot of cookery, particularly in South India. Each cookery had slight differences in the vernacular name. However, there were a few exceptions of cookery-used millets and rice. For example, the boiled grain was widely called *chawal* or *bhat*, but it was also known as *annam* in Andhra Pradesh, *sadam* and *soru* in Tamil Nadu, and *anna* in Karnataka. Further, the thick porridge was called *onda* in Orisa, *samkati* in Andhra Pradesh, *kali* in Tamil Nadu, *mude* and similar names in Karnataka, and *dhido* and *senne* (Sherpa) in Nepal. The thin porridge was called *bari* in Uttar Pradesh, *peja* in Madhya Pradesh, *ambil* in Maharashtra, *jau* in Orissa, *ganji* in Andhra Pradesh and Karnataka, and *kulu* in Tamil Nadu. *Mave* was a raw flour food that was offered to Hindu gods and made only from foxtail millet and rice in Tamil Nadu.

Farmers have an appropriate awareness of the status of millets and their relative weeds in the domestication process. This symbiotic process between millets and farmers was reconstructed by integrating field observations, botanical experiments, archaeological data, and linguistic sources. There were various vernacular names in the Eastern Ghats and Southern Deccan Plateau, where Indian millets were widely cultivated with their relative species today. It is obvious that the several names in the Old Indo-Aryan and Dravidian languages are related to the vernacular names of millets. *Brachiaria ramosa* and *Setaria pumila* have been domesticated from the weeds that grew around upland rice fields via a mimic companion weed type that was mainly related to *Panicum sumatrense* and other grain crops. *Brachiaria ramosa* has become an independent crop in pure stands, while *S. pumila* grows as a mixed crop with *Panicum sumatrense* and other millets.

Consequently, *Brachiaria ramosa* and *Setaria pumila* are so-called “tertiary crops,” meaning, they are a double secondary crop for the other millets and upland rice. The order of first occurrence of millets from historical sites generally supports this evolutionary process. This domestication center of millets covered the Eastern Ghats and Southern Deccan Plateau.

The world history of foods was summarized in Table 51. Because the human had been the most

conservative in their food preferences compared with the other fashions. The food ingredient had been changed very slowly. In the Paleolithic age, people had eaten mainly barley porridge, in the next neolithic age, they had eaten mostly wheat. The bread made by 100% wheat was luxury foods, only high-ranking person were able to eat them. There were many kinds of discriminations between the rulers and the ruled people. For example, farmers cultivated wheat/rice, but they did not eat wheat/rice and ate oat/millets until the Middle Ages. The ordinary people had eaten the foods made from millets, oat porridge, rye bread as maslin. When maize and potato had been introduced from New World, European people did not eat them. They were accepted maize as a new food in 16 C. They had fed potato to pigs, while maize to cows in the 19th century. After that European people had become to eat much volume of meat. Because the Agri-pastoral Complex had developed, and people became to eat much meat and chicken of domesticated animals. The human population was explosive increase, and also in connection with the change to meat eaters, the populations of domesticated animals/plants have increased.

The crop coevolution with human had processed from the subsistence for survival/existence, next the tax paid in grains for the rulers until the Middle Ages, and then merchandise for city people in modern times. In human history, the grain crops, especially millets had been exposed discrimination and prejudice. Therefore, millets had been called Orphan crops, neglected and underutilized species (Pdulosi et al. 2022). However, the United Nations General Assembly at its 75th session in March 2021 declared 2023 the International Year of Millets. I had a short speech, “A historical sketch of millets in Japan” in the webinar.

Table 51. Historical discrimination and prejudice on foods (cereals/beans/tubers)

Region/People	Main food	Wheat	Rice	Maize	Millets	beans	Tubers
Europe	wheat	grain spilit		not food for European			not food for European
Ruler	tax	bread wheat		New ruler had eaten bread wheat, subjuugated people had eaten emmer/spelt wheat			
City people	not cultivate	bread wheat					
Farmer	cultivate	barley, rye, oat			foxtail/common millet	pea, lentil, faba, chick pea	potato for pig
Livestock	feeding	increase in meat - eating	culms,leves, weed, wild	feeding for cattle			
Wild animal	predation	wild animals and plants					
Africa	sorghum, pearl millet						
Ruler	tax	Wheat					
City people	not cultivate	Wheat					
Farmer	cultivate		wild grains		finger/pearl millet, tef, sorghum,	cawpea	Yam
Livestock	feeding		culms,leves, weed, wild				
Wild animal	predation	wild animals and plants					
Asia	rice, taro						
Ruler	tax		rice				
City people	not cultivate		rice				
Farmer	cultivate	wheat, barley	rice		foxtail/common millet, finger millet, backwheat	soy, azuki	taro, Yam, potato, sweet poteto
Livestock	feeding		culms,leves, weed, wild		grains for human, stems/leaves for cattle	culm and weed, wild	
Wild animal	predation	wild animals and plants					
Meso/South America		maize, potato					
Ruler	tax		maize				
City people	not cultivate		maize				
Farmer	cultivate		maize	saui, mango, quinoa, amaranth	kidney beans, groundnut		
Livestock	feeding						
Wild animal	predation	wild animals and plants					
Japan			*mochi* new year, *inadama*			small new year, *abo/hibo*	
Ruler	tax		rice, *tonoamamu* (*Ainu*)	rice			
City people	not cultivate		rice				
Farmer	cultivate	wheat, barley				millets, *shiruamamu* (*Ainu*)	
Livestock	feeding		culm and weed, wild			culm of Japanese barnyard millet	
Wild animal	predation	wild animals and plants					

History of processing tools

We have grown traditionally six species, such as five annual millets, foxtail, common, finger, Japanese barnyard millet, sorghum, and an exception of perennial Job's tear. They are mostly annual C4 plants self-fertilized with the exception of perennial Job' tear. Also, our ancient people had grown Japanese barnyard, foxtail, and common millet in the Jomon period, about several thousand years

ago in Japanese Archipelago. Eight species have waxy varieties, which are foxtail, common millet, sorghum, Job's tear, barley, maize, rice, Poaceae and amaranths, Amaranthceae.

Japanese barnyard millet might have been the domestication process in North Japan after the Holocene. Also, these potteries contained the ancient soybean and azuki been seeds inside. In an early Yayoi village (or final Jomon period), our ancestors had grown rice in a primitive paddy field, foxtail millet on the mound at the same time in Nabatake Ruins, about nine hundred years B.C. Even today, a few farmers cultivate Japanese barnyard millet at both upland and lowland fields in north Japan. Moreover, the other farmers cultivate it on the burnt field in south Japan. The same cultivating system of finger millet as Karnataka, India has been conducted at Yamanashi, Central Japan. For example, finger millet is transplanted their seedlings from the nursery both in India and Japan. These villagers were had conserved many local varieties of millets. This area was noted for their villagers' longevity and well health in the world. Moreover, they have practiced many kinds of cookery from taro, millets, barley, wheat and rice. These are very similar food style both in Japan and in India.

Nakao (1967) described the basic agricultural complex as "to stomach from seeds," which were composed of many elements including tools and methods as shown in Figure 80. Moreover, the complex consisted of the intelligences in each mind as illustrated in Figure 81.

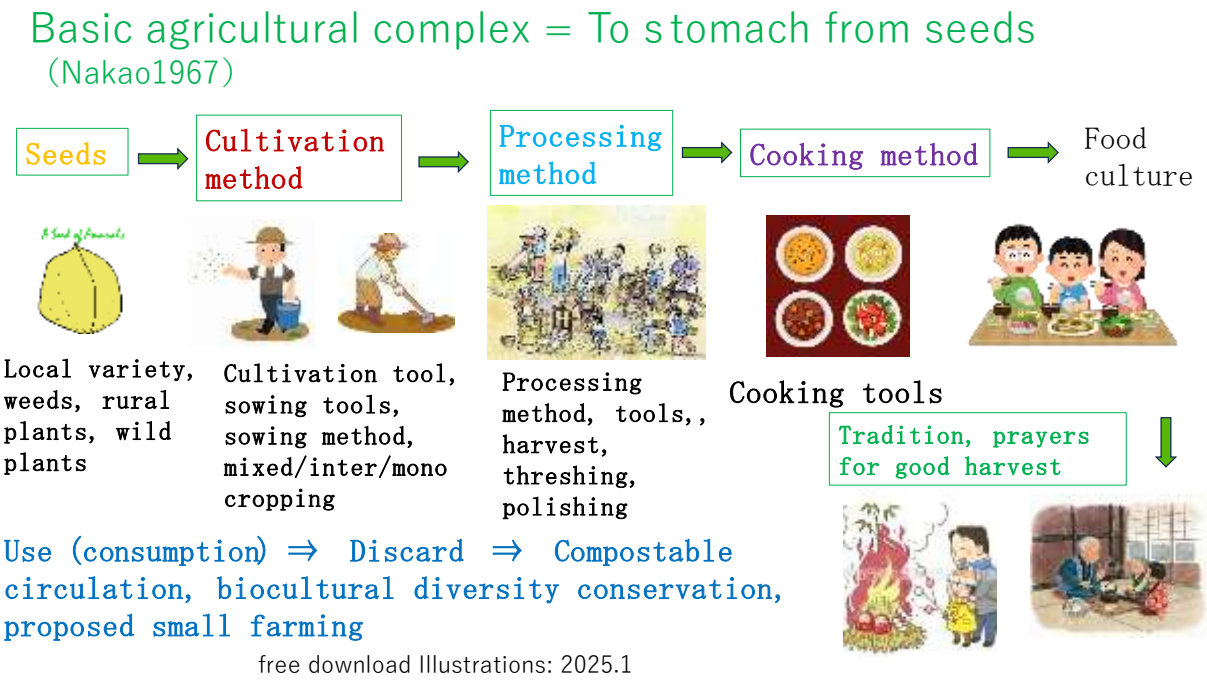


Figure 80. Basic agricultural complex

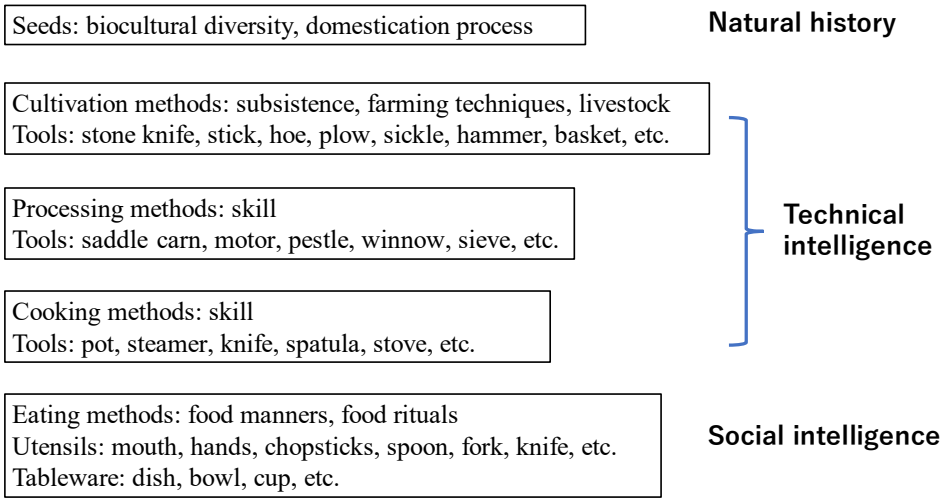


Figure 81. Natural/ artificial evolution of tools and methods

Darwin cooked with hot rocks in an earth oven and called the art of making fire probably the greatest [discovery], excepting language, ever made by man. He understood the value of cooked food. But he showed no interest in knowing when fire was first controlled. His passion was evolution, and he thought fire was irrelevant to how we evolved. Most anthropologists have followed Darwin's assumption that cooking has been a late addition to the human skill set, a valuable tradition without any biological or evolutionary significance. A century later, cultural anthropologist Claude Lćvi-Strauss produced a revolutionary analysis of human cultures that implicitly supported the biological insignificance of cooking. The implication by Lćvi-Strauss that cooking had no biological meaning was widely touted. No one challenged this aspect of his analysis. Cooked food does many familiar things. It makes our food safer, creates rich and delicious tastes, and reduces spoilage. Heating can allow us to open, cut, or mash tough foods. But none of these advantages is as important as a little-appreciated aspect: cooking increases the amount of energy our bodies obtain from our food. We should indeed pin our humanity on cooks. We are tied to our adapted diet of cooked food, and the results pervade our lives, from our bodies to our minds (Wrangham 2009).

The processing tools are illustrated historically in Figure 82 (Kimata 2025, Miwa 1989, Nakao 1967). Our human beings had used and developed many kinds of tools for our daily lives. Our civilization had been developed and utilized by the main three inventions, that is, fire, tools and languages. We had used the natural objects, water, wind, stone, soil, wood and metal for making tools. The processing of grains had been conducted by them. Those tools or machines had become efficient, but the mechanism had not been much changed in principle. Ancient Japanese peoples had used many kinds of tools made from stones, soil, wood, and so on (Figure 83). These clay pots had included soybeans and azuki beans in the middle age of Jomon culture (Katsusaka-style of Central Japan), 5000 BP（Nasu 2018）.

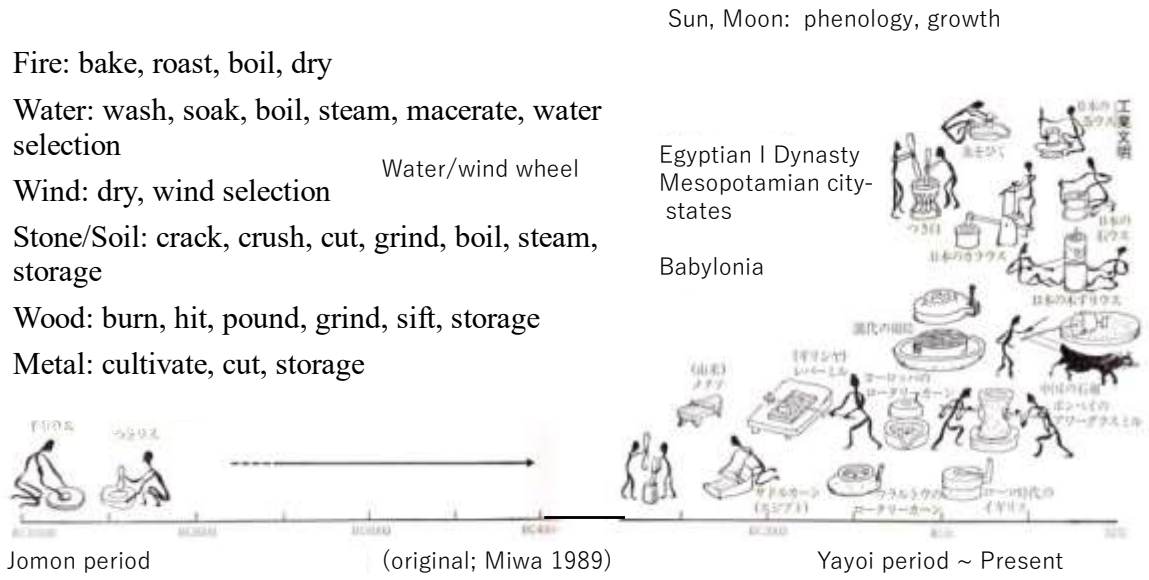


Figure 82. History of processing tools for grain

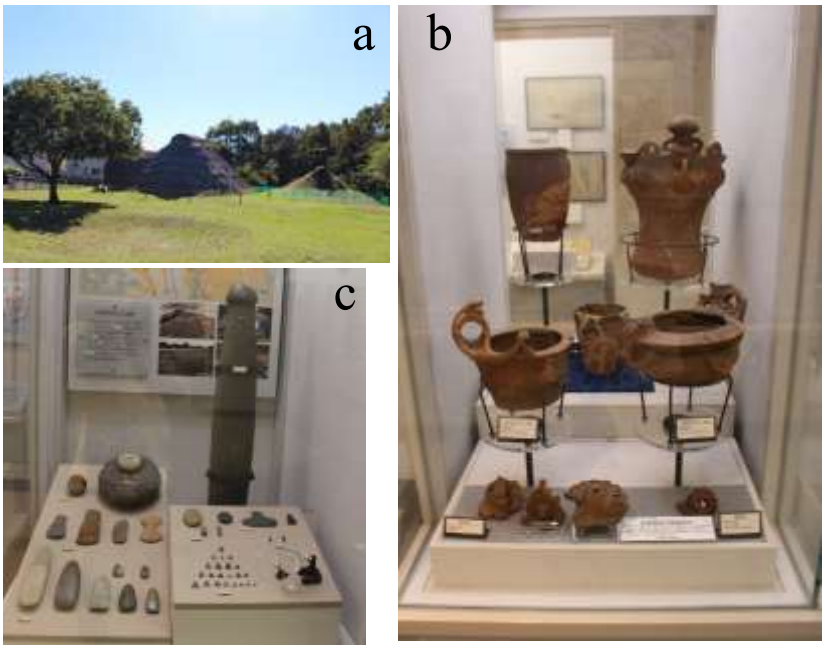


Figure 83. Many kinds of tools excavated at the Katsusaka Jomon ruins

a, a village; b, stone tools; c, clay pots.

The agricultural tools of India are shown in Figures 84~86. Even today, those traditional tools are used by farmers in the countryside. On the other hand, the large-scale agriculture such as American style has been adopted since the Green Evolution.

Local farmers use many kinds of farming tools. The seeds are sown in rows. Traditionally, threshing has been by animal foot pressure, the modern method is carried out by cars on the road as shown in Figure 84. Farmers grind grains into powder by millstone, which had been very similar tool to

ancient saddle quern (Figure 85). Housewives have many kinds of cooking tools and fleshly polished them (Figure 86).

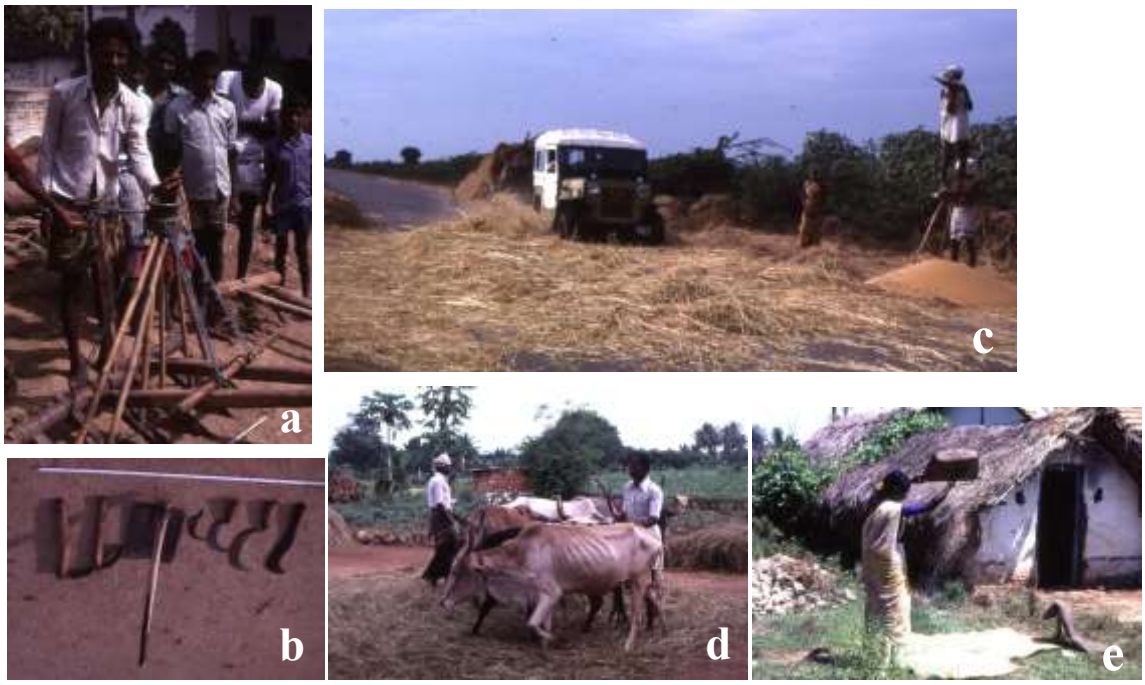


Figure 84. Tools for cultivation and processing

a, sowing tool; b, cultivating tools; c, threshing on the road; d, threshing by caw stepping pressure; e, wind selection by winnowing basket.

Figure 85. Milling tools

a, millstone for finger millet in Karnataka, India and b, saddle quern excavated at the Katsusaka Jomon ruins in Japan

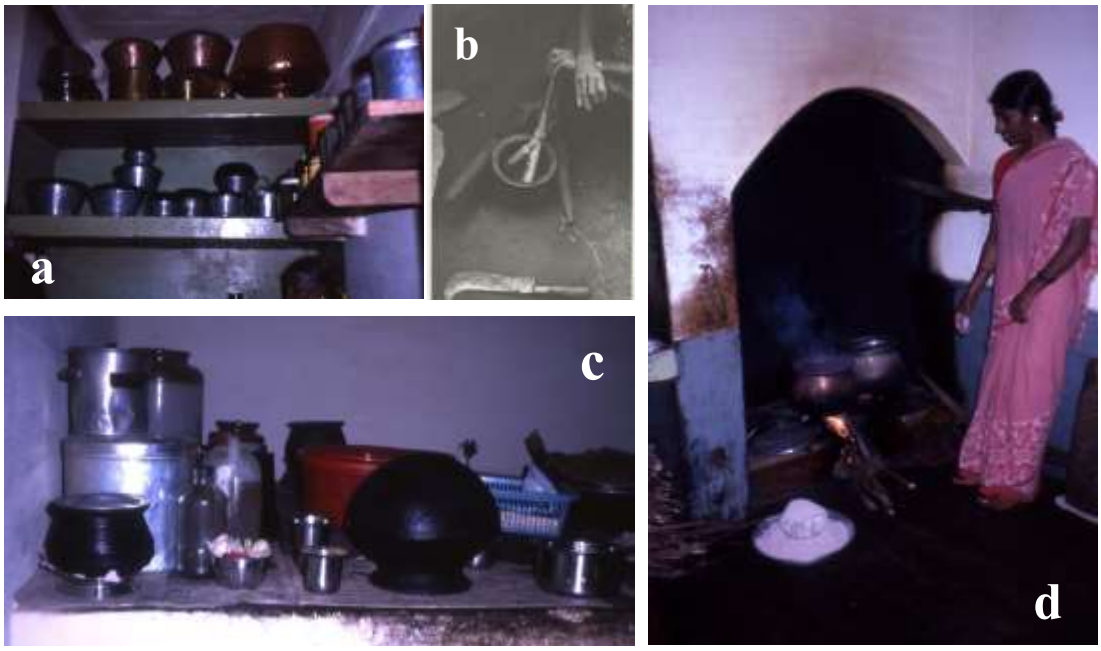


Figure 86. Kitchen utensils

a, pots; b, kneading pin for *mudde* and cooking knife; c, pots and cups; d, stove.

Processing of millets and the faith in Japan

The traditional motors are used very rarely for processing grains even at mountain villages in Japan Today (Figure 87). Farmers have hulled, polished, and milled grains to make powder, then pounded waxy rice to *mochi*, and soy bean to *miso*.

There was a very interesting point comparing with the water wheel of Japan and it of India, that is, the former rotated vertically, but the latter turned sideways.

Moreover, the agricultural rituals have been handed down (Figure 88). Japanese Emperor has offered ears of rice and foxtail millet to their ancestors in the *niiname-sai,* an important harvest ceremony in the Imperial Palace. The chosen farmers grow them and offer their ears and grains to Emperor. There are waterwheel, millstone and wooden mortar

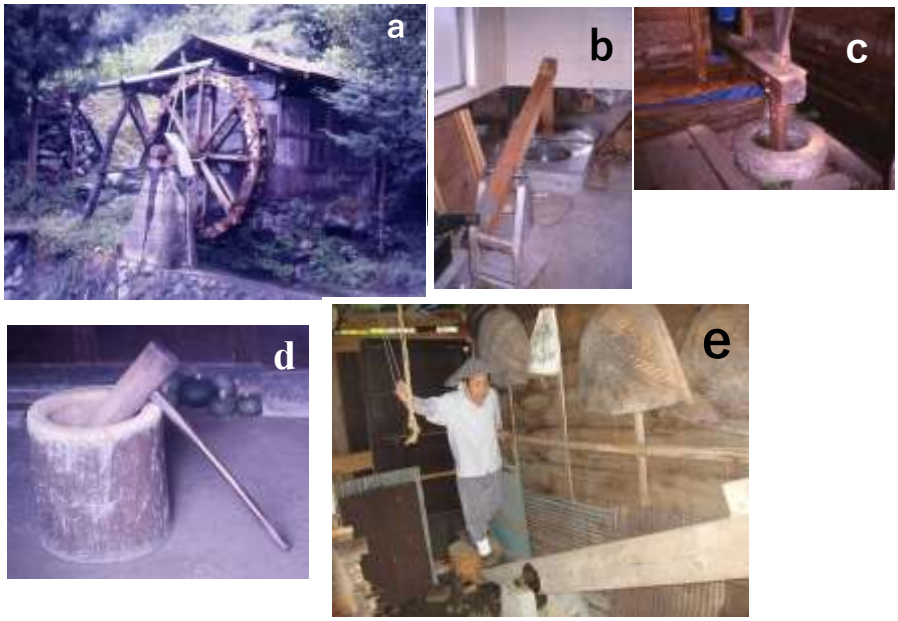


Figure 87. Processing motors in Japan

a, water wheel at Saihara, Yamanashi; b, stone motor at Tsushima, Nagasaki; c, at Saihara; d, wooden motor at Saihara; e, stone motor at Ikawa and Shizuoka in Japan.

We have two special ways of parboil processing and wet milling. Farmers boil the grains of Japanese barnyard millet in Japan, and little millet etc. in India before the de-husking. After the parboiling, we can easily de-hask small grains of millets. They make the flour of grains through the wet milling process to daily use and the offering for their gods in Japan and India.

Many villagers have celebrated traditionally the little new year offerings by making a figure called *kado-otoko* attached the spikes of foxtail and Japanese barnyard millet and farm tools, straw bags, etc., made from *nurude*, Chinese sumac for the god of farmers (Figure 88a). It means that some millets are sacred crops like rice and they are the same status both in Japan and India. Some village people have offered a kind of *sushi*, *yamame* fish staffed boiled grains for *Osuwa-sama* god of hunters (Figure 88bcd). Foxtail millet is offered for *niiname-sai*, an important harvest ceremony held by Japanese Emperor. He offers the sacred food like rice and foxtail millet to his ancestors in the ritual at the palace of Emperor (Figure 88e.f.g.h).

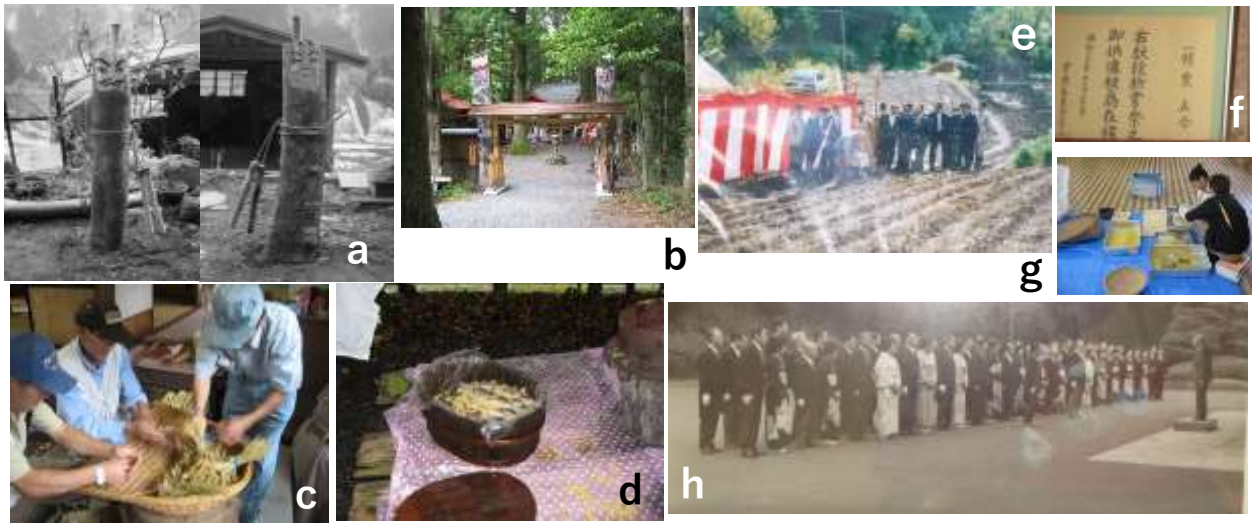


Figure 88. Agricultural rituals of millets in Japan

a, *katsunbo* gods will promise farmers good harvest in the coming autumn. They have spikes of foxtail and Japanese barnyard millet, also sickle and hoe. b, *Osuwa-sama* god shrine for hunters; c, threshing foxtail millet by hands; d, offer a kind of *sushi*, *yamame* fish staffed boiled grains for the god. e/f/g/h, offer foxtail millet for *niiname-sai,* an important harvest ceremony held by Japanese Emperor at Kosuge, Yamanashi pref. (1986 and 2008) and in the Imperial Palace.

Dispersal hypothesis of the agricultural complex in the Indian subcontinent

There were many land routs of Central Eurasia, in spite of travel disorders, for example, Himalaya mountains, Takla Makan deserts, Kazakh Steppe, numerous rivers, lakes, and so on (Figure 89). Our ancestors had traveled long distances following roads both ways from west (Europe) to east (India and China) and from east to west. The crops had been historically dispersed to both sides by them for thousands of years.

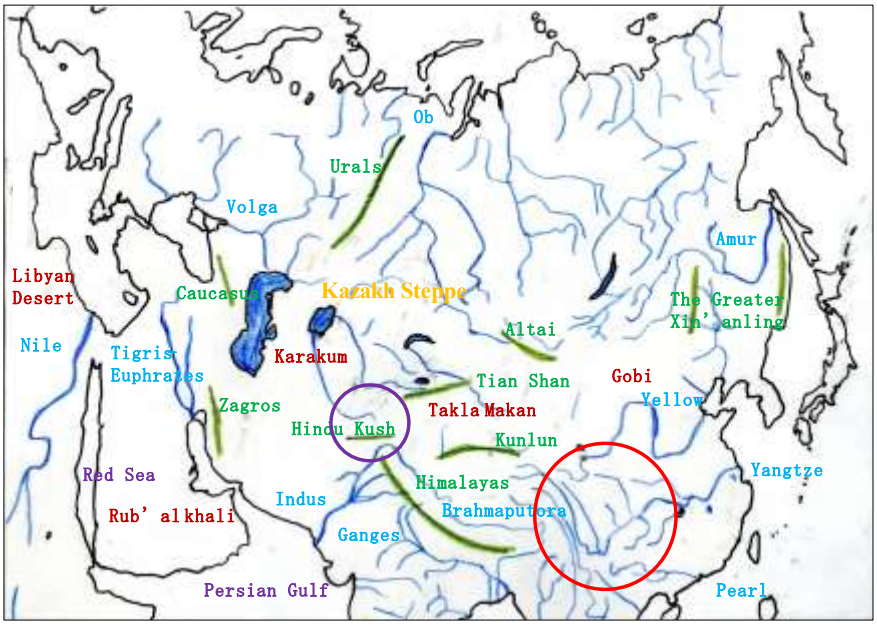


Figure 89. Mountains, rivers and deserts in Central Eurasia

On the contrary, there were many ocean currents connected among Africa, The Indian subcontinent, South East Asia, Philippines and Japan (Figure 90). As long as our ancestors had ridden the ocean current, they had come or gone everywhere through the islands scattered in the oceans. The land routes were connected from Africa to Eurasia. Also, the ocean currents had been important dispersal ways, for example, both sides between Africa and South Eastern Asia via The Indian subcontinent, and then from those places to Japan, via Philippines.

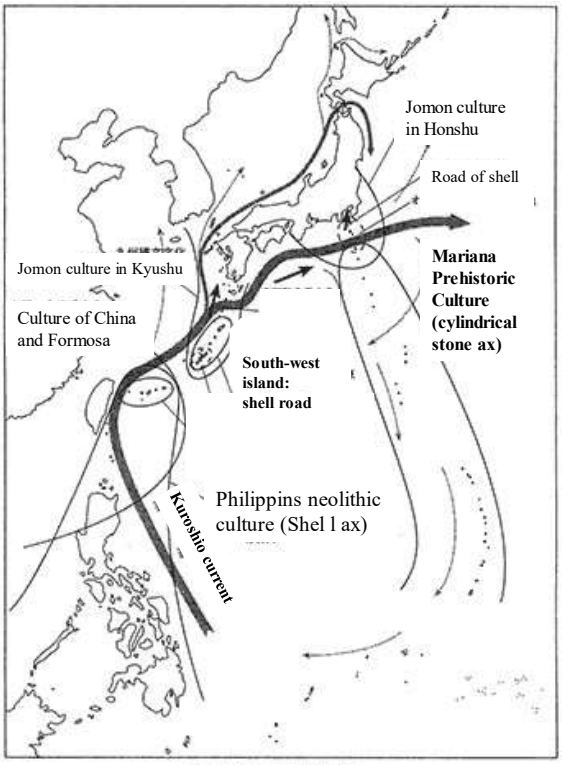


Figure 90. Ecosphere of Kuroshio Current in the Prehistoric period

Banana propagates mostly by the way of tillers or basal shoots. Sugar cane propagates by culms. Taro propagates by tubers or basal shoots. On the contrary, the wild perennial rice has propagated by the way of rhizomes and seeds in wet lands (Katayama 1987). That was the vegetative planting agricultural complex. The wet lands were so-called beginning paddy fields. Ancient people had tried to transplant tubers, culms of taro, sugar cane, banana vegetatively and rice seedlings around a mother parent. Nakao (1967) and Sasaki (1994) have explained again as follows.

1) Characteristics of Vegetative Planting Agriculture: ① No seed farming, ② utilization of polyploid, ③ absence of legumes and oil crops, ④ grip stick farming, ⑤ from back yard to burnt field, ⑥ utilization of Job's tear, ⑦ Distribution of the Vegetative Planting Culture to Africa.

<correction points> I want to revise their hypothesis in new knowledge. I would like to explain the new model on Agricultural complex around the Indian subcontinent.

The characteristics of Vegetative Planting Agriculture Complex are mostly effective, the domestication process of rice had been in the continuous development stage of these complex. Because rice was a perennial plant growing wetland, the mother plant survived and surrounded by

many seedlings. In other words, the wet land was an origin of rice paddy field. The tillers had been transplanted vegetatively and also seedlings had been transplanted in the same way of banana, sugar cane, taro, and so on in South China. On the way to the mountain area in Zomia, rice had been selected artificially to an ecological annual and varieties of upland rice under the domestication process. While rice had been dispersed to Deccan Plateau, it had been developed the annual cropping system in the rainy season of Monsoon. Also, Job' tear and *kodora* (perennials) had become the companion weeds, then they had been domesticated as the secondary crops.

2) Finger millet was the most basic element among all millet species on Savanna Agricultural Complex. Foxtail millet and common millet had been grown in the arid area from North Western India to Western Pakistan. *Kolati* (*Setaria pumila*, syn. *S. glauca*) was grown in Bombay state. The domesticated place of foxtail millet was India. The two groups of barn yard millet were domesticated in India and then dispersed toward the North-East, domesticated in the Temperate region of evergreen broadleaf forest, moreover, dispersed to Japan.

<correction points> Finger millet had maintained a profitable position in an index plant of Savanna Agricultural Complex. However, I considered that foxtail millet and common millet had been domesticated in the steppe area, the south foot of Tien Shan Mountains (Chapter 4). Many millets domesticated in South India, and those secondary crops such as *samai*, *jangora* (*Echinochloa frumentacea*), *korne*, *korati*, etc., had become more stronger against aridity than mimic companion weeds with rice (Chapter 5). On the contrary, Japanese barnyard millet (*hie*, *Echinochloa utilis*) had been domesticated from a wild annual at wetlands, Noth Japan. The weeding was perfect in Savanna Agriculture, because of applicating row sowing method. Therefore, Nakao (1967) had made a definitive statement that the secondary crops had not domesticated in Savanna Agriculture, and it had been true. In other words, these secondary crops were domesticated from mimic companion weeds on the rain-fed fields and upland fields during the dispersal of rice from East to South India (Kobayashi 1987, 1989, 1991, Chapter 5). However, Japanese barnyard millet, *Echinochloa utilis* had domesticated in Jomon period of North Japan, while *E. frumentacea* had done in India.

3) The crops were completely different from weeds in Savanna Agricultural complex, which were in a competitive relationship. On the contrary, the weeds in wheat fields were not always an antipathist enemy. Many weeds grown in wheat fields were become to many secondary crops, but it was nothing of the secondary crops in the Savanna Agricultural complex because of the row sowing and perfect weeding.

4) The Savanna Agricultural Complex had been begun in the dry tropical Savanna. An ancestral people had gathered and eaten the wild grains of Poaceae for food during summer monsoon. After the complex had dispersed to heavy rainy area, the people had met the aquiherbosa of Poaceae, and then they had selected a wild rice which were particularly excellent among hygrophytes. Rice was just a millet growing in paddy field. It was not necessary to distinguish specifically between rice and the other millets.

5) The domestication of rice had been begun in India as a component of the Savanna Agriculture Complex, that is to say, rice was one of millets. Rice had been specially grown on paddy fields in the plains. After that, the varieties of upland rice had developed in the Assam mountains where was spread to the westward.

<correction points> Indian millets had domesticated from mimic companion weeds with upland rice

as the secondary crops, but were not domesticated in Savanna Agriculture complex. It had Rice Agriculture Complex were derived in South China secondly from the Vegetative Planting Agriculture Complex.

6) Rice is transplanted, and also finger millet is transplanted from South India (Figure 91) to Nepal (including even Japan). Usually, finger millet had sown directly. Because farmers transplant finger millet in July of Monsoon rainy season, these seedlings take roots in good condition even on upland field. The transplant practice of rice had been imitated the practice of finger millet (Figure 91). Therefore, it was a possibility that the transplanting of rice had been begun in Bihar, East India. <correction points> On the contrary the transplanting of finger millet had been imitated the practice of rice.

Figure91. Cultivation practice of finger millet

a, nursery; b/c, transplanting in paddy fields; d, harvesting by ear cutting.

7) Assam mountains was the area of Vegetative Planting Agriculture complex, where the farmers had grown tubers. After farmers were introduced a new crop like upland rice, they had cultivated rice using *hori* stick for dot-spreading by the same method of tubers. Then upland rice was become on a level of millets such as foxtail and common millet. This upland rice was accompanied with waxy variety of Job' tear. These cereals were all annuals (actually perennial and ecological annuals)

8) It was not suitable for storage to gather the immature grains of wild grasses, because those were watery. Therefore, farmers needed to eat at once or to process these grains. For example, the parboil method was widely practiced and then made chiura (beaten rice) in India. Also in Japan, farmers had practiced parboil method (*shiromushi*/*kuromushi* methods) for Japanese barnyard millet.

Major revision on the Vegetative Planting Agriculture Complex

Now I must think about the major revision on the Vegetative Planting Agricultural Complex, and then need to consider Rice Agricultural Complex. Even if Nakao's hypothesis (1967) is very excellent, it has passed near 60 years ever since the proposal. During this time, the plenty of research papers have been published on the origin of agriculture. We need to reconsider the above eight issues.

The dispersal routes of banana and then rice had been overlapped in South China and Zomia (Figures 92, 93 and 94; Bellwood 2005). Rice Agricultural Complex had been fostered around these

regions such as the advanced type. The bananas are large, stooling herbaceous perennial plants which are propagated vegetatively by means of corms. The typical seedless edible banana is therefore a product of two evolutionary processes: parthenocarpy and sterility, both essential. Edibility evolved first in wild *Musa acuminata*. The species is very variable and taxonomic evidence indicates that the primary center was the Malay peninsula (Simmonds 1995).

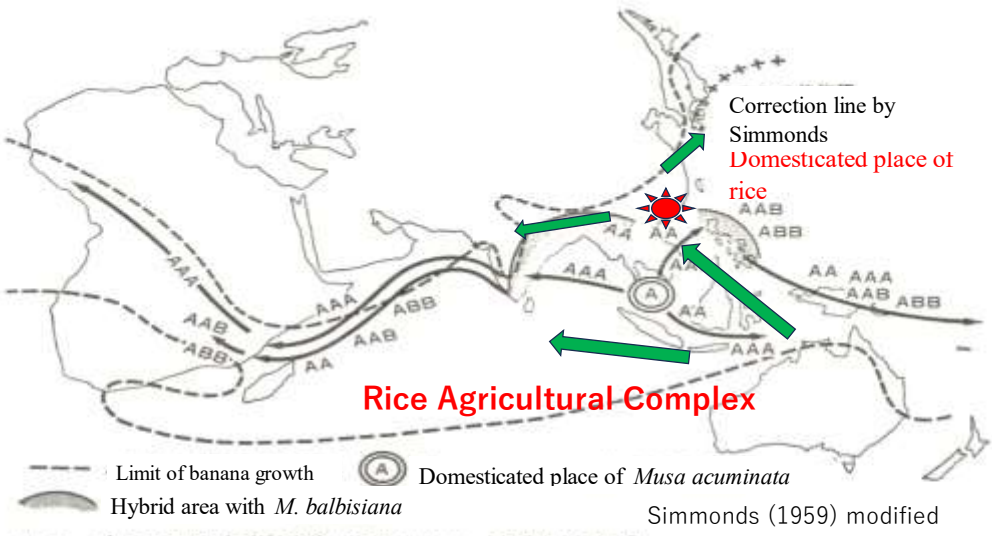


Figure 92. Domesticated places and distribution of bananas and rice agricultural complex

Sugar canes are large perennial grasses which are propagated vegetatively by stem cuttings. The first plant crop is usually harvested about a year after planting, with subsequent ratoon crop harvested annually until yield reduction necessitates replanting. Sugar canes are of tropical origin, but interspecific hybridization, principally with the wild species *Saccharum spontaneum*, has extended the geographic range of economic sugar cane production. *Saccharum spontaneum*, the most primitive *Saccharum* species, is believed to have evolved in the Himalayan foothills of northern India. *Saccharum officinarum* dispersal to the east across the Pacific and to the north-west and in the course of time somatic mutation increased its diversity (Roach 1995).

The coconut palm is an important crop throughout the humid tropics at altitudes up to 600 m. It will grow, but not fruit well, in drier climates, at higher altitudes and in subtropical latitudes. It seems reasonable to suppose that early human habitation on tropical sea coasts and islands would tend to be where wild coconuts already existed. About 3000 years ago, the progenitors of the Polynesians left the Melanesian region by boat and went into the Pacific and Indian Oceans (Harries 1995).

In Yang-shao, China it was certainly later than foxtail millet and probably later than panic (syn. common) millet. In Harappan India, it was later than wheat and barley. In the wet tropics of south-eastern Asia, it was later than the original agricultural system, founded on taro, yams, banana, Coix (syn. Job's tear), and other crops. Both upland and swamp rice invaded the southeastern monsoon belt and to a large extent replaced the agriculture based on roots and trees. Taro was apparently a wet-field crop long before rice appeared in the area. Small but well-constructed terraces were built and flooded by water led to them by canals. It has been suggested that rice was domesticated from

a weedy race infesting wet-field taro plantations. We have no evidence for or against this theory at the present time, but if this process took place, it was probably in addition to the domestication of rice in the savanna zones. While rice became woven into the religious ceremonies, rites, and worship practices of rice-eating people. Many Hindus consider wild rice a more appropriate cereal offering at the temple than cultivated rice. Rice cakes, rice balls, rice wine, rice flour, and whole-grain rice are all used as thanks offerings (Harlan 1977).

Also even today, those banana, sugar cane, taro and coconut palm are grown on nearby wet-fields (Figures 93 and 94). Taro is one of the world's oldest food crops, dating back over 9,000 years. Often seen as an orphan crop, taro's global importance manifests most commonly at the local level through its role in traditional food systems. It is the farmers and communities who are the guardians of taro (Rao et. al., 2010). An orphan crop is local significance but one that is not traded as an international commodity, and attracts limited attention for research. One of the reasons behind taro's importance at the community level is that, with the exception of the skin, all parts of taro plants are edible.

Along with its importance as a source of food, in many cultures, taro is a sacred plant with high prestige and strong cultural and symbolic importance. In the Pacific, taro presented on formal occasions, in domestic or agricultural rituals, and as part of religious celebrations. Apart from dalo (syn. taro), the owner is also collecting varieties of a range of other crops including breadfruit, bananas, plantain, coconut, yams, wild yams, giant taro, sugar cane etc. The experiential and educational aspects of the agritourism enterprise include more than just tourists. Biodiversity conservation programmes will only succeed in the long run when receptive locals take responsibility and run the programmes (Berno 2020, Hunter et al.).

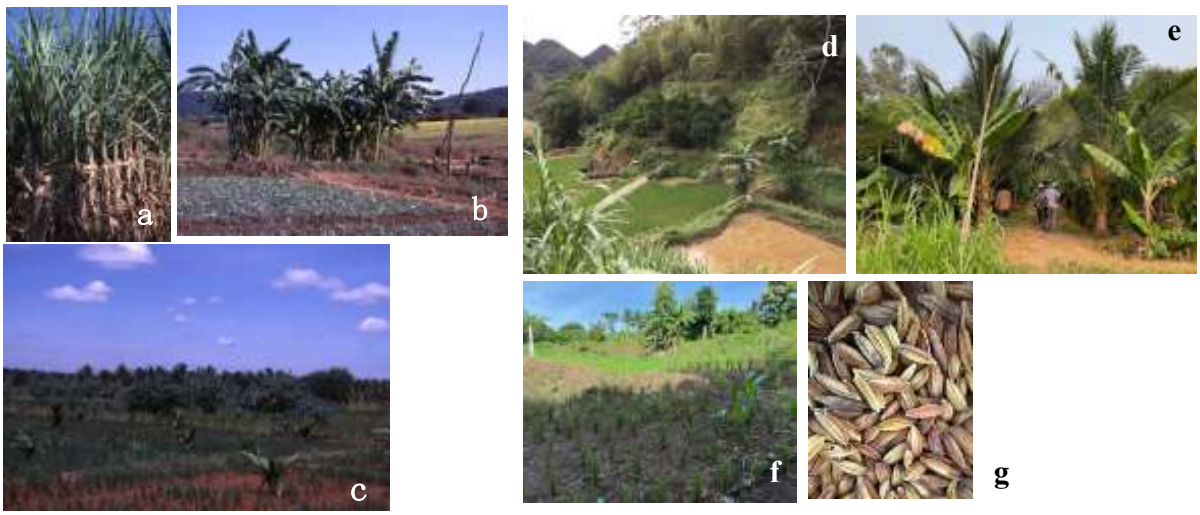


Figure 93. Sugar cane, taro and banana grown nearby rice paddy fields in Eastern India.
a, sugar cane; b, banana; c, coconut palm in eastern India. d, paddy fields near by banana; e, coconut palm and taro in Vietnam; f, paddy fields by banana and g, a traditional variety of rice in Thailand (photographs by M. Ino and K. Nakagomi 2025)

We cook many kinds of foods using common millet, for example, boiled grains, waxy dumpling

mochi, non-waxy gruel in Eurasia. I have studied the domestication process and dispersal route of common millet, based on the ethnobotanical data (Chapter 4). This species might have cultivated around Central Asia, and then had dispersed toward both Europe and China before 6500 BC. Several millets, finger, common, foxtail millet have dispersed up to South East Asia. East Asian people like waxy foods made from cereals historically.

Also in the Northern Philippines, this premier food crop serves many local purposes. Boiled rice (*hinamal*) is the centerpiece of any proper meal and fermented glutinous (waxy) varieties yield a rice beer (*bavah*) essential for most ritual and other special social occasions. A meal consists at least of a starch staple (*anon*), preferably rice. Another boiled grain or root crop (most frequently sweet potato tubers, *lapne*) may serve as a substitute. Thire starch staples are consisted of rice (non-waxy, 82%), Sweet potato (30%), Taro (3%) and the others including millet. During a previous period of equal or greater duration, terracing for rice and taro cultivation, combined with shifting cultivation of yams, taro, other root crops (excluding sweet potato), and some millet and sorghum, may have been practiced in all the main Ifugao valleys. For centuries prior to that period the more gently sloping valleys possibly attracted small populations of shifting cultivators using some pond-field terracing for taro. Accelerated agricultural and demographic change probably occurred after the introduction of the sweet potato in 16th century (Conklin 1980).

Millets had been dispersed from mainland Asia to the Sunda islands as shown in Figure 94a (Kano 1946 modified by Kimata). However, Japanese barnyard millet had not dispersed there. There were 7 species, which had waxy varieties, that is, rice, foxtail millet, common millet, sorghum, Job' tear, maize, and barley. Japanese barnyard millet has not a waxy variety traditionally. The waxy varieties of grains have the characteristics of sticky texture (*mochi*) which are similar to those of banana, taro, and yam in the vegetative planting culture. As illustrated in Figure 94b (Sakamoto 1989), because South Eastern peoples had liked those taste preferences of the sticky texture, the waxy varieties of rice (then including more 6 cereals) had developed their biocultural diversity in the domestication process under the influence of the Vegetative Planting Culture.

We can eat the raw food of yam (tubers), banana (fruits) and sugarcane (culms). However, taro and grains were need to such heat as boiling and baking by fire on their cooking method.

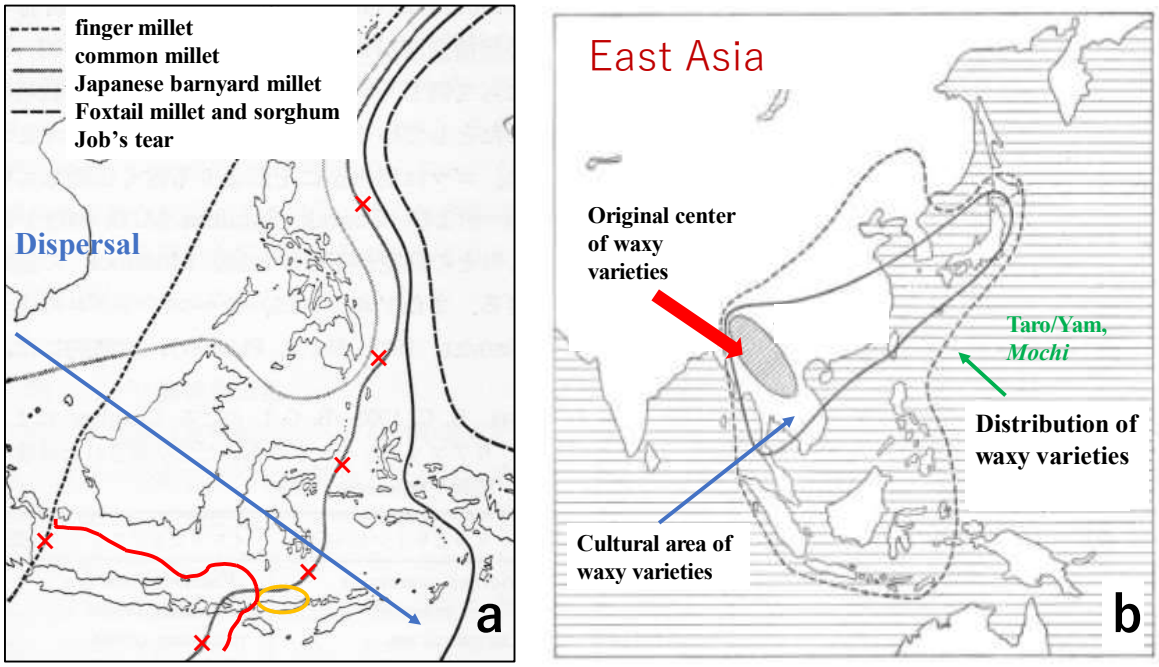


Figure 94. Dispersal of millets and waxy varieties around the South Eastern Asia

a, Kano (1946) modified; b, Sakamoto (1989) modified

A very unique study on the comparative linguistics between Tamil and Japanese (Table 52) was conducted by Oono (2004). There were many similar terms on farming and processing between Tamil and ancient Japanese. He had thought that these terms on processing and food were dispersed from Tamil to South Japan in the early Yayoi period (Figure 23). Moreover, he had considered that some culture with rice and foxtail millet had come to Japan from Tamil by riding the ocean currents in about early Yayoi period.

Table 52. Comparison of farming terms between Tamil and ancient Japanese

English	Tamil	ancient Japanese	today Kanji
levee	acc-u, kur-ampu	az-e, kur-o	畔
bund	an-ai	un-e	畝
paddy field	vayal, tampal	tamb-o	水田
field	pat-ukar	fat-ake	畑
slash-and burn cultivation	kum-ari	kob-a	焼畑
mountain fermland	puravu		山の畑
foxtail mille	av-ai, tinai, enal	af-a	粟
rice	nel、enal	sin-e, ina, ine, nel	稲
paddy rice	pu	fo	水稲
rice grains	nel	ni	稲粒
rice offered to a god	kum-ai	kum-a	供米
bran	nukk-u	nuk-a	糠
boiled rice	arici	meshi	米飯
shitogi	cit-ai	sit-ogi	粢
mochi	mot-akam	mot-ifi	餅
mochi flour	ar-ai	ar-e	餅粉
porridge	kal-i	kay-u	粥
loose porridge	amp-ali	am-ari	ゆるい粥
parched rice	pori		炒り米
residue	kat-i	kas-u	糟

Nakao (1976) had proposed the hypothesis on the development of agriculture complexes and their systematic diagram in Eastern Asia (Figure 96). He had appointed that the millet agriculture complex showed especially 4 features as follows. 1) Farmers have grown annual crops, without tubers. 2) They cultivated many kinds of legumes, 3) melons and fruit vegetables, and also 4) oil crops. Therefore, this complex was the cultivation system for good nutritional balance.

Sasaki (1994) had summarized Nakao' theory as follows. The grains had been indispensable tools to processing, which clay pots, saddle quern, wood motor, pestle and so on, as mentioned above (Figures 80~88). Moreover, because the farmers had needed careful weeding, the companion weeds were never on millet fields and then had not been domesticated the secondary crops. The millet agriculture complex could not be developed the large field. Rice was merely one of millets on wetland, it was part of the Svanna Agriculture and was influenced by the Vegetative planting Agriculture Complex. Therefore, the rice agricultural complex did not exist.

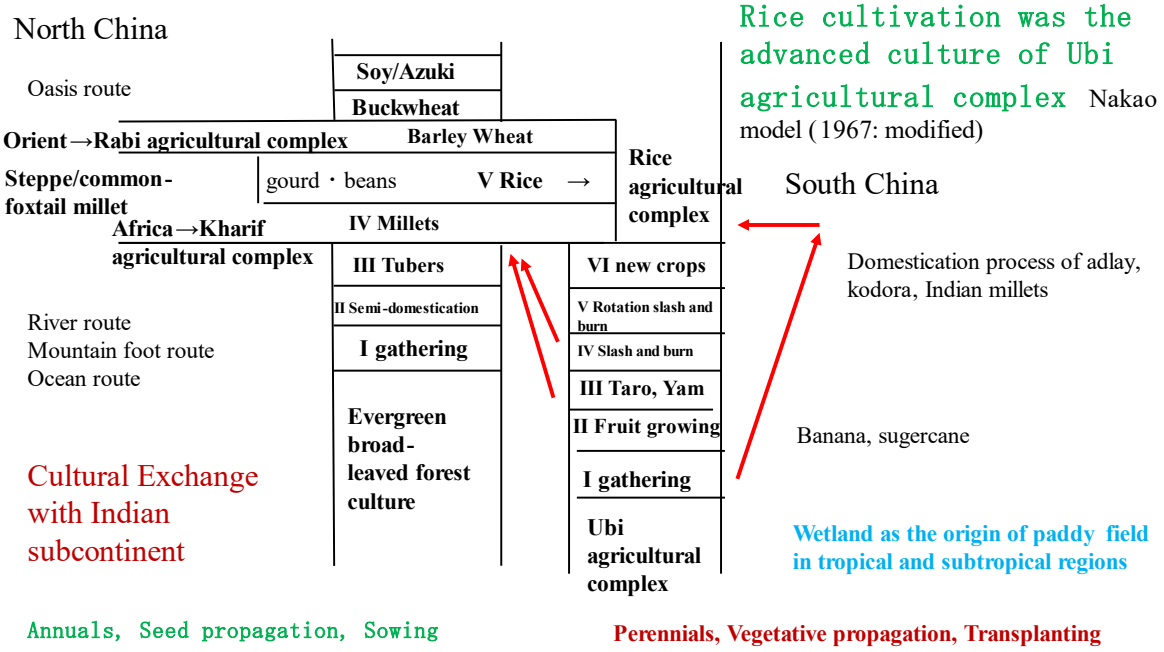


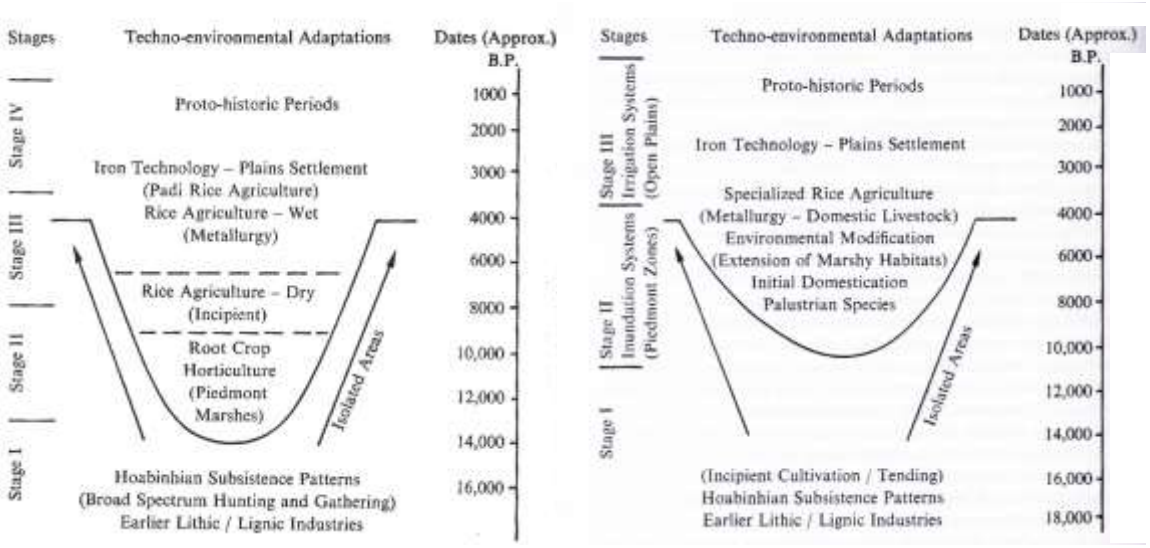
Figure 96. Development of agriculture complexes and their systematic diagram in Eastern Asia

Sasaki (1994) had clearly denied that rice and taro had domesticated in the same wetland, but some European researchers had considered that the domestication of rice had been occurred in the same place such as wetlands (Saur 1952, Werth 1954, Harlan 1977, Gorman 1977, Conklin 1980).

For example, Gorman (1977) had presented two models of the development of rice agriculture. In the Stage II of Figure 97A, the phase of root crop horticulture, is at present only a postulated reconstruction. If it did exist as an initial phase of domestication, the time placement shown below would seem fairly accurate. Stage II would continue until the initial forms of rice cultivation were sufficiently successful to allow a replacement of root crop horticulture by rice agriculture, rice then becoming the primary subsistence crop. Data now available suggest that initial cultivation of rice was an adaptation of the lower piedmont, with the settlement of the more central plains taking place only after the introduction and development of iron technology.

In Figure 97B, these alternative views rice and root crops (primarily taro and Yams) as “sister domesticates,” with their joint initial domestication beginning prior to B.P. 9000, probably in palustrine zones somewhat in piedmont areas of mainland southeastern Asia. In both models, dry rice is viewed as a later adaptation, dependent upon the initial domestication of rice as a ‘wet’ crop. At what point, in terms of either time or the process of cultivation, this secondary adaptation to swidden began remains unknown. The entrance of adzes and ceramics into upland Hoabinhian sequences might well represent the upland spread of this adaptation. Both models are quite speculative.

The findings of recent southeastern Asian researchers are organized in terms of the stage division of the second model. The crossing of the first marked the initial domestication of certain key palustrian species (e.g. taro and rice) and caused a shift in settlement from upland areas to piedmont zones where more agriculturally productive habitats could be expanded artificially with minimal effort.



A: Gorman model I (1977) **B: Gorman model II**

Figure 97. Models on the development of rice agriculture

Direct evidence of the early evolution of the cultivated rice is fragmentary and often controversial. Although many workers have supported that the Indian subcontinent is the ancestral home of *O. sativa*, the earliest archaeological evidence from India goes back only to 2500 BC. On the other hand, rice remains of the Neolithic period in China have been dated to 8500 BP and the recorded history of rice cultivation in that country goes back to the third millennium BC (Chang 1995). Nakao' excellent hypothesis needs to revise a little, because of the new research results demonstrated above. Especially, the domestication place had been changed from Bihar (India), via Yunnan-Guizhou Plateau (China), Yangtze River (China), to Peral River (China) over the past 60 years. I would like to proposed a new model on development of rice farming/agriculture as shown in Figure 98.

Wild rice was a perennial plant inhabited in wetland, it reproduced both by vegetative (parent plant and culms) and sexual (seeds). Ancient peoples had collected grains of wild perennial rice for food, which had grown naturally in wetlands. After that they had domesticated rice around Pearl River, which had become an ecological annual plant, and propagated mostly by transplanting seedlings (both vegetative and seed). The wetland was just original paddy fields. Moreover, the rice cultivation had been dispersed to the mountainous area of Zomia and Eastern India, and then peoples had grown rice on upland, around hills and mountainous areas.

When rice had dispersed to Eastern Ghats, India, many kinds of millets had been domesticated from companion weeds and mimic companion weeds as shown in Figure 99. The detail domestication process is explained in chapter 5.

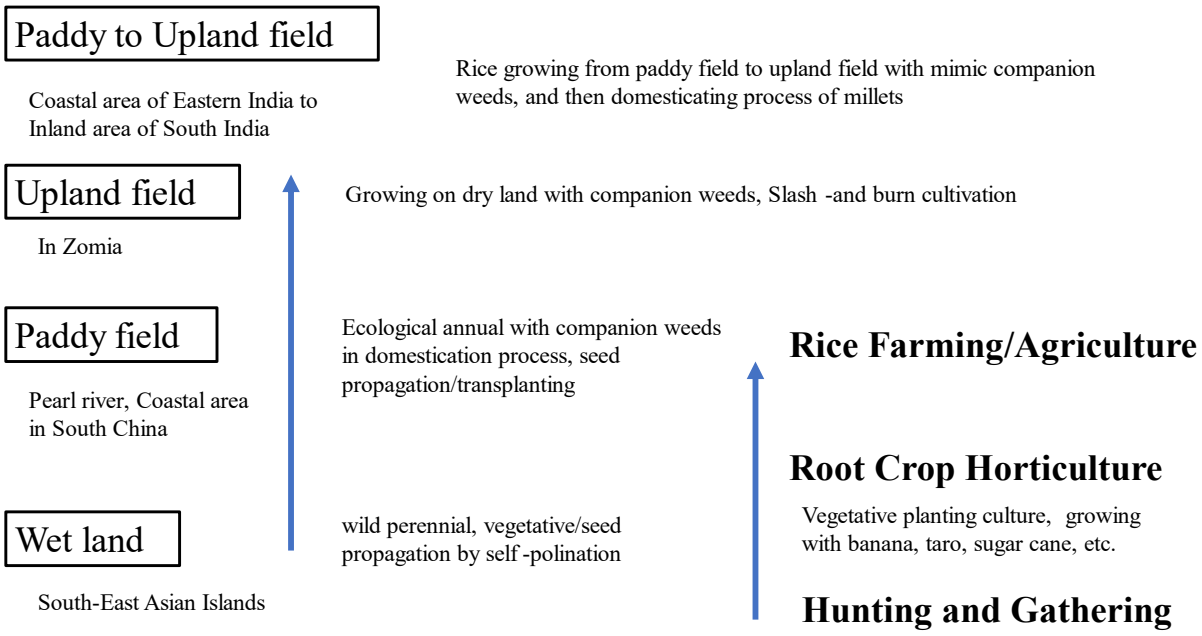


Figure 98. A new model on development of rice agriculture

Comparison among the primary crop, the secondary crop and the tertiary crop

Our team studied the domestication process and dispersal routes of Indian millets. An outline of the research results is given below. The typical domestication processes were compared among the primary (common millet), the secondary (little millet, *Panicum sumatrense*) and the tertiary (*korati*, *Setaria pumila*) crops as shown in Table 53. It was called the primary crop, which was domesticated directly from the wild plant. The secondary crop had been cultivated via companion weed from weed, for example, oat and rye were able to tolerate for cold, while millets were able to tolerate for dry.

Common millet had been domesticated about B.P. 8500~8000 and had dispersed to all around the Eurasia continent, little millet had been domesticated about B.P.4000, and then *korati* had been domesticated about B.P. 3800 shown in Table 50. They were very interesting and present progressive processes on crop evolution/domestication in the Indian subcontinent. These three species are all C4 and annual plants. The ancestor species of common millet might be disappeared, but I inferred that it was *Panicum miliaceum* ssp. *ruderale* based on my field research and experimental data (Kimata 2015). Also, I expect that the subspecies grow as a large population around Tianshan mountains and in the Kazakh steppe even now. In the steppe of Central Asia, there are many grasslands where are sunny days all year long. The annual mean precipitation is 250~750 mm. The companion weed type was distribute to maize fields in European country. The dispersal range of this species was all in Eurasia. The vernacular names of common millet were very diverse in the Eurasia, but the others were a few. The cooking methods of common millet were also so many.

Little millet（*samai*） and *korati* were the secondary crops domesticated from their companion weeds with rice. The wild ancestral subspecies of little millet grows on such wetlands as levees and paddy fields which are a staple annual cycle ecologically in India. The weed of *korati* is at cosmopolitan which grows in broad area in a wide area of Eurasia (including Japan, *kine-nokoro* in

Japanese name). But *korati* grows in small population at limited habitat, where is at the floor under sparse forest. These two crops are polyculture with the other crops. Their vernacular names are not so very diverse and region-limited. *Korati* is usually harvested, processed and cooked together with *samai*.

Table 53. Comparison among the primary (common millet), the secondary (little millet) and the tertiary (*korati*) crops

Cracteristics	*Panicum miliaceum*		*Panicum sumatrense*		*Setaria pumila*	
	present	process	present	process	present	process
	Main crop		**Secondary crop**		**Tertiary crop**	
Wild type	presence	existed	presence	existed	presence	existed
Population size	big	greater	small	small	small	small
Number of seeds	more	many	more	many	a few	a few
Gathering and use	feed	grain, feed	existed	a few	a few	a few
Weedy type	presence	shattering	presence	shattering	presence	shattering
Mimic weed type to different local crop	absent	shattering	presence	shattering	presence	shattering
Mimic weed type to same local crop	rarely	shattering	presence	shattering	presence	shattering
Hybridization between crop and mimic weed	rarely		always		always	
Mixed cropping with different local crop	rarely		presence		always	
Harvesting with different local crops	absent		presence		always	
Cooking with different local crops	rarely		rarely		always	
Distribution area of domesticated and wild types	world-wide	steppe in Eurasia	around India		part of South India	Eurasia
Diversity and distribution of local names	world-wide	Central Asia	Indian subcontinent	East India	limited area in India	South India

Kodora, *Paspalum scrobiculatum*, was domesticated since about 2000 BC in India. This species is cultivated throughout the Indian subcontinent, but mainly in Madhya Pradesh. Ecological and morphological characteristics were compared using 32 accessions (including weed forms) of *Paspalum scrobiculatum*. In addition, the relationship between plant pigmentation and mimicry of rice was observed in 16 accessions, including six accessions collected from upland rice fields. Domestication process of the secondary crop to upland rice was discussed (Ishikawa unpublished). This species shifted from perennial to annual and obtained crop-like traits by accessions with rice cultivation. Both amplified fragment length polymorphism (AFLP) analysis and nucleotide sequence variation of the chloroplast trnK/matK region divided cultivated accessions into two groups, northern and southern groups. The northern cultivated accessions were genetically related to weed accessions collected from upland rice fields in Orissa. However, southern cultivated accessions showed close relationships to both accessions of upland rice fields in Orissa and the weed type in southern states. Furthermore, two alternate hypotheses for the origin of *Paspalum scrobiculatum* were summarized: (1) kodo millet was domesticated once in Orissa and then diffused to inland and southern states and (2) kodo millet was domesticated in Orissa and somewhere in the southern states of India, independently (syn: kodora, Ishikawa 2007).

Jangora, *Echinochloa furumentacea*, is cultivated for food, fodder, and as an emergency crop

in India, Nepal, and Pakistan. Its ancestor is a weed, *Echinochloa colona*, found in paddy fields. Morphological characteristics and AFLP analysis results of seven accessions of *Echinochloa colona* and 42 accessions of *Echinochloa furumentacea* were compared. On the basis of the results, the place of origin was assumed to be around Bihar, and then it was distributed to Tamil Nadu via Karnataka (Kagami unpublished).

Samai, Panicum sumatrense, is cultivated for food and fodder in India, Nepal, Sri Lanka, and Myanmar. Its ancestor is a weed, *Panicum sumatrense* subsp. *psilopodium*, found in paddy fields. Morphological characteristics and AFLP analysis results of 38 accessions and 281 herbarium specimens of *Panicum sumatrense* were compared. On the basis of the results, the place of origin was assumed to be Eastern India, and it was then distributed in Southern India (Otsuka unpublished).

Korne, *Brachiaria ramosa*, is grown by very extensive farming for food in only India. Its ancestor is a weed found in paddy fields. Morphological characteristics and AFLP analysis results of 70 accessions of *Brachiaria ramose*, including both weed and domesticated types, collected from Pakistan and India were compared. On the basis of the results, the place of origin was assumed to be the southern part of Orissa, and it was then distributed in the Deccan Plateau via Tamil Nadu Otsubo unpublished).

Korati, *Setaria pumila*, is a cosmopolitan weed, but its domesticated type is mostly grown by mixed cropping with *Paspalum scrobiculatum* or *Panicum sumatrense* in only India (Kimata et al. 2000). This domestication process is discussed in detail above (chapter 4).

In conclusion, the domestication process of millets based on field observations (Kimata et al. 2000), experimental results (Kimata 2015a, 2015b), and these linguistic sources is provided in Tables 32~39, chapter 5. This domestication center of millets covered the Eastern Ghats and Southern Deccan Plateau. Although this process is quite complicated among millets and their relatives, it is very effective for understanding the domestication by a secondary origin via weed and mimic companion weed types. Oats and rye were the secondary crops of wheat that developed cold tolerance (Vavilov 1926), while Indian millets were secondary crops of upland rice that developed drought tolerance. *Bachiaria ramosa* tolerates drought better than *Setaria pumila*, and it became an independent crop. *Setaria pumila* is almost always grown with little millet, but it seems to grow singly when little millet fails to grow in severe droughts. Both species are so-called tertiary crops, meaning, they are a double secondary crop for the other millets and upland rice. The millet domestication process indicates the importance of weed–crop complexes and basic agricultural complexes as a plant–man symbiosis (Shinohara and Nishitani 2011).

The integrating hypothesis for the dispersal route of Indian millets is illustrated in Fig. 80 on the basis of the results. *Echinochloa furumentacea*, *Panicum sumatrense*, and *Paspalum scurobiculatum* were secondary crops to upland rice. First, their ancestral plants were companion weeds derived from the relative weeds that invaded paddy fields in humid regions of Eastern India. Second, the companion weeds became insurance crops in upland rice fields, and they spread to a dry region in the Deccan Plateau (Kobayashi 1987, 1989). *Brachiaria ramosa* and *Setaria pumila* were so called ‘tertiary crops’ because they were secondary crops to other millet species domesticated from their relative weeds in upland fields. On the other hand, *Digitaria cruciata* has been recently derived from the relative weed grown in maize or vegetable fields, Kashi Hill, Meghalaya, and is limited to the same area (Singh and Arora 1972).

Tentatively, Indian millet species were domesticated in the process of diffusion from humid paddy fields in Eastern India to dry upland rice fields in the Deccan Plateau, Southern India.

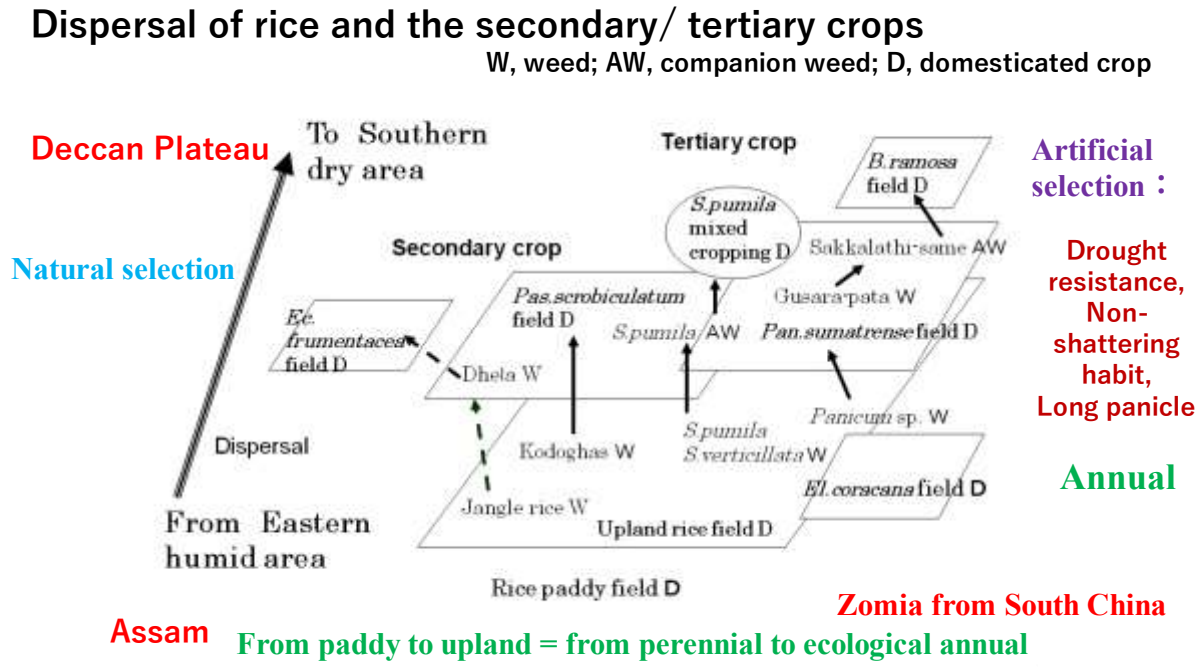


Figure 99. A model on the dispersal of rice and domestication process of the secondary/tertiary crops in The Indian subcontinent

Domestication process of millets and dispersal route in The Indian subcontinent

The domestication process of millets based on field observations (Kimata et al. 2000), experimental results (Kimata 2015a, 2015b), and these linguistic sources is illustrated in Figure 99. This domestication center of millets covered the Eastern Ghats and Southern Deccan Plateau. Although this process is quite complicated among millets and their relatives, it is very effective for understanding the domestication process by a secondary origin via weed and mimic companion weed types. Oats and rye were the secondary crops of wheat that developed cold tolerance (Vavilov 1926), while Indian millets were secondary crops of upland rice that developed drought tolerance. *Brachiaria ramosa* tolerates drought better than *Setaria pumila*, and it became an independent crop. *Setaria pumila* is almost always grown with little millet, but it seems to grow singly when little millet fails to grow in severe droughts. Both species are so-called tertiary crops, meaning, they are a double secondary crop for the other millets and upland rice. The millet domestication process indicates the importance of weed-crop complexes and basic agricultural complexes as a plant-man symbiosis.

The indigenous millets of the Indian subcontinent have been domesticated across their ranges of present-day cultivation for some 3500 years (de Wet et al. 1983a; Fuller 2002; Pokharia 2008). These millets include *Paspalum scrobiculatum* L. (*kodora*, *kodo* millet), *Echinochloa frumentacea* Link (Indian barnyard millet), *Panicum sumatrense* Roth. (little millet), *Brachiaria ramosa* (L.) Stapf. (*korne*), *Setaria pumila* (Poir.) Roem. & Schult. (*korati*; syn. *Setaria glauca* (L.) P. Beauv.), *Digitaria cruciata* (Nees) A. Camus (*raishan*), and *Digitaria sanguinalis* (L.) Scop. (Chandra and

Koppar 1990; de Wet et al. 1983a, b, c). The former three species seem to be secondary in origin, through the mimic and/or companion weeds of the rain-fed paddy and then upland rice in Eastern India. The next two species, *Brachiaria ramosa* and *Setaria pumila*, were domesticated as secondary crops that were associated with the other millets via their mimic companion weed types in South India (Kimata et al. 2000; Kimata 2015a, 2015b, Kobayashi 1987, 1989). *Digitaria cruciata* was domesticated in the late nineteenth century by Kashi natives in Meghalaya and is cultivated only in the Kashi Hills (Singh and Arara 1972). Unfortunately, *Digitaria sanguinalis* has disappeared, and its origin is not clear.

In contrast to other millets, which were probably domesticated in humid Eastern India, *Brachiaria ramosa* and *Setaria pumila* have adapted to the dry climate of the semi-arid tropics. *Brachiaria ramosa* was cultivated in the hot, arid red soil region of Southern India, whereas *Setaria pumila* was cultivated in the hot sub-humid ecoregion in red and lateritic soils of Orissa, as well as in the hot semi-arid ecoregion on red loamy soils of Southern India (Sehgal et al. 1992). *Brachiaria ramosa* tolerates drought better than *Setaria pumila*, it has undergone a specializing adaptation to arid regions, and it has nearly attained the tertiary domesticated phase (Kimata et al. 2000). On the other hand, the local varieties of *Setaria pumila* have adapted to drier fields in Southern India than in Orissa. *Setaria pumila* was normally grown with *Panicum sumatrense*, but it seemed to grow singly when the latter failed to grow in severe droughts, which was observed in our 1987 survey. This possibly suggests that *Setaria pumila* could become an independent crop. *Brachiaria ramosa* is an underutilized millet that is restricted in cultivation today to dry areas in the two border districts of Tumkur and Anantapur in the states of Karnataka and Andhra Pradesh, respectively. *Brachiaria ramosa* is cultivated in pure stands as a sole tertiary crop, while *Setaria pumila* is still cultivated by mixed cropping with *Panicum sumatrense* and other grain crops as a minor domesticated plant. A tertiary crop is a type of double secondary crop of *Panicum sumatrense* and others and a secondary crop of upland rice.

The methodological concept of the "agricultural basic complex," the so-called "from seeds to stomach" idea, was proposed by Nakao (1967) while studying the origin of agriculture. A domesticated plant always is accompanied by the cultural complex, which includes cultivation practices, processing, cookery, religious use, vernacular names, and other aspects (Kimata and Sakamoto 1992). Bellwood and Renfrew (2002) recently proposed and examined their "farming/language dispersal hypothesis" cooperative across the disciplines of archaeology, linguistics, and genetics from a broad comparative perspective. These millets and their relative weeds also have many vernacular names in each locality and language. This report is concerned with the reconstruction of their domestication process, particularly *Brachiaria ramosa* and *Setaria pumila*, from the point of view of their vernacular names with reference to linguistic archaeology, because good linguistic data have not yet been sufficient for the indigenous millets (Fuller 2002; Southworth 2005).

Therefore, I must integrate the factual material collected by my-self in order to a new hypothesis model of domestication process and dispersal. Those are new insight and experience through the field works and experiments in botany, cultural anthropology, linguistics, and archeology.

Sakamoto (1989) had put forward the seven places of geographical origin on domesticated plants, and additionally two places of Eastern India (EI) and North Japan (J) as shown in Figure 100.

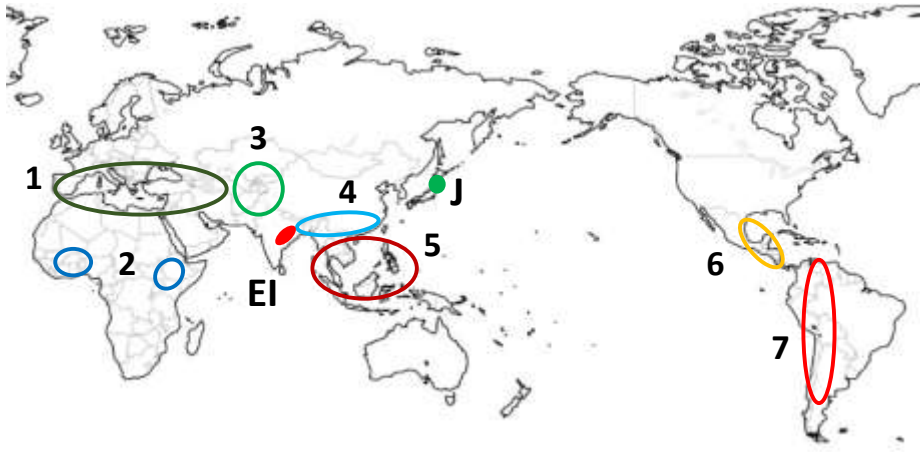


Figure 100. Six places of geographical origin on domesticated plants, which had added Central Asia, Eastern India and North Japan

1, Mediterranean; 2, African savanna; 3, Centra Asian steppe; 4, Southern China and Zomia; 5, South Eastern Asia; 6, Central America; 7, South America; J, North Japan; El, Eastern India. (Sakamoto 1987, modified by Kimata)

Graeber and Wengrow (2021) has suggested the new independent centres of domestication. Archaeological science has all this. Experts now identify between fifteen and twenty independent centres of domestication, many of which followed very different paths of development to China, Peru, Mesoamerica or Mesopotamia. To those centres early farming must now be added, among others, the Indian subcontinent (browntop millet etc.); the grasslands of West Africa; the central highlands of New Guinea (banana, taros and yams); the tropical forests of South America; and Eastern Woodlands of North America.

I compiled the characteristics of four main agricultural complexes and three additions in Afro-Eurasia into Table 53. The four main complexes (Nakao 1967) were Rabi farming (mainly wheats), Kharif farming (African millets and yams), Ubi farming (tubers and banana) and New World farming (maize and tubers). Three new additions are Nomadism in Great steppe (common millet), Indian Agricultural Complex (wheats, millets and rice) and Rice farming (rice).

The domestication process had been extremely complicated regarding both genetical and ecological traits, for example as illustrated in Figure 99. Also, the dispersal range had been very wide of geography and very long of history on the earth (Zohary and Hopf 2000.).

Proposal for an enlargement model on the agricultural complexes around the Indian subcontinent

I would like to attach three expansions on four main agricultural complexes around the Indian subcontinent as shown in Table 54. Because the original places of rice and common millet became clear, we must modify Nakao' hypothesis partially. Here, we centered the Indian complex on agriculture, and added two expansive complexes, Nomadism in Great Steppe and Rice Farming in Tropics. The interesting point are as follows. ① Basically, all the complexes contained as components which were grains, beans and oil crops. However, nomads eat grains and drink daily

milk products, while livestock feed their culms and leaves. Therefore, it is no problem that they do not intake the protein from beans. ② There is no edible tubers in Rabi Agriculture Complex. ③ Rice, Job' tear and *kodra* are perennial plants in wetlands, but ecological annuals on upland fields. ④ During the differentiation process of upland rice, the mimic companion weeds of Indian millets were domesticated in Eastern Ghats area. ⑤ The kinds of crops and vegetables had been selected by topography, elevation, rainy season. ⑥ Farming systems are crop rotation, mixed cropping and intercropping in the mountainous fields. ⑦ There were no tubers in Savanna area and Great Steppe. ⑧ Sowing systems are broadcast, furrow, spot sowing and transplanting. ⑨ Because the yield of grains had increased and stored in large quantities, Agriculture had begun and provided the tax grain based on local economy to the ruler, and then his city-states were formed (Scott 2017).

Table 54. Four main agricultural complexes and more added nomadism, Indian agricultural complex, or rice farming.

Farming format	Rabi farming	Karif farming	Nomadism		Rice farming	Ubi farminng	New world farming	
	Mediteranean Agriculrural complex	Savanna Agricultural complex	Great steppe	Indian Agricultural complex	Rice Mixed culture	Vegetative Planting Agricultural complex	Mesoamerica Agricultural complex	South America Agricultural complex
Characteristics	West Asia・Mediterranean costal are, wheat farming in winter	Africca and Indian subcontinent, Millet farming in summer	Central Eurasia, Nomadism	Complex farming accepted/ transformed from the Afro-Eurasia	Combined Ubi farmings in East and South Asia	Tubers farming in East-South Asia	Vegetative Planting Agriculture and Maze in summer	
Place of origin	Orient	Around Niger river and Eastern Africa	South mountain foot of Tienshan in Central Asia	Indian subcontinent	Southern China	around Malay peninsula	Mexiico, Mesoamerica	Andes, and flatland in East mountain foots
Distribution	Mediterranean, Orient, Afro-Asia	Sahara, Ethiopia, West India	Central Asia, Pakistan, North-Western India,Afghanistan, Iran	Inndian subcontinent, South foot of Tian Shan	East Asia, from South-East Asia to East India and Sri Lanka	Oceania, Malaysia, India and Central Africa	North America	North West of South America
Race	Caucasoid	Negroid	Caucasoid, mixed race	Mixed race, Aryan, Dolavida, Draviidian, Mongoloid, Austro-Asia	Mongoloid	Mongoloid	Mestizo	Mestizo
Environment	mediterranean climate, winter rain, flatland	sabanna climate, summer rain, flatland	steppe climate, summer rain, desert, mountain foot, oasis	savanna, steppe, tropical rain forest; flatland, hill, mountain foot	evergreen brooadleaf tree, deciduous mixed forest tree, tropical forest, flatland/wetland, flood plain, mountain	tropical rain forest	tropical rain foorest	Temperate summer rain
Crop ecology	winter annual, seed propagation	summer annual, seed propagation, vegetative propagation	summer annual, seed propagation		ecological annual, seed propagation, vegetative propagation	perennial, vegetative propagation	summer annual/seed propagation, perennial/vegetative propagation	
Major grains	wheat, barley, rye	finger millet, sorghum, pearl millet, rice	common millet, foxtail millet, oat	wheat, barley, rice, millets	rice	adlay		maize, mango
Major beans	chickpea, lentils	cowpea, kidney bean	lentils	pigeon pea, mung bean	soybean, azuki bean	pigeon pea, mung bean	kidney bean	peanut, kidney bean
Major tubers		yam		yam, taro	taro (satoimo)	yam, taro	sweet potato	cassave, potato
Major oilseeds	canola, mustard, safflower, linseed, olive	oil palm, niger seed, castor bean		mixed	mustard	coconut palm, sesame	cotton, sunflower	sea-island cotton, peanut
Drinks		coffee		tea	Korean ginseng		cacao	mate tea
Others	vegetables, fruits	melon, watermelon	hemp, garlic, onion, carrot, apricot, apple, pear, plum, almond, pistachio	vegetables, fruits		banana, sugarcane, fruits, spices	amaranthus, cotton, pepper	quinoa, amaranthus, tobacco, cotton, pepper
Established period (around)	8000 B.C.	2500 B.C.		4500 B.C.	4500 B.C.	8000 B.C.	5000 B.C.	
Farmland use	crop rotation, grass fallowing	continuous holticulture	nomadism in summer			shifting cultivation, bush fallow		
Seeding format	broadcasting	row sowing		roadcasting/mixed cropping, row sowing/intercropping, transplanting	transplanting	hill sowing, transplanting		
Farm implements	spade ard	hoe				digging stick		
Processing	kiln (powdered food)	polishing by vertical pestle		parboiling	*Shitogi* (wet milling), grain food	raw food, stoneware		
Food economy	abandance surplus, easy transportation	a little surplus	for self-sufficient			surplus, dificult transportation		
Establishment of a city state (around)	3000 B.C.			2500 B.C.	1600 B.C.		1000 B.C.	1500 B.C.

Murdock（1959）, Guyot（1964）, Nakao（1967）, Harlan（1979）, Sakamoto（1987）. Their hyposesises were modified.

The Indian subcontinent is diverse both linguistically and agriculturally. Within the context of the Renfrew/Bellwood hypothesis, the three major language groups of central and peninsular India have all been attributed to such language-farming dispersals, including Indo-European, Dravidian and Austro-Asiatic (the Munda sub-family). These hypotheses, however, have not been considered in detail in relation to either the archaeological, archaeobotanical or linguistic evidence relating directly to early agriculture in South Asia. In southern India, the archaeobotanical evidence indicates that a basic set of native staples occurred throughout the Southern Deccan. Browntop millet (*Brachiaria ramosa*) and bristley foxtail (*Setaria verticillata*), both grasses of uncommon but localized occurrence on wetter soils in the semi-arid Deccan savanna zones. Other millets of peninsular Indian origin have also been recovered in small quantities, although they may not have

been cultivars, including little millet, *kodo* millet, *sawa* millet and yellow foxtail millet (Bellwood 2005; Fuller 1999, Fuller et al. 2001, Fuller 2002).

I want to condense my new model of the integrating hypothesis for the dispersal route of Indian millets on the basis of the results as illustrated in Figure 101. *Echinochloa furumentacea*, *Panicum sumatrense*, and *Paspalum scrobiculatum* were secondary crops to upland rice. First, their ancestral plants were companion weeds derived from the relative weeds that invaded paddy fields in humid region of Eastern India. Second, the companion weeds became insurance crops in upland rice fields, and they spread to dry region in the Deccan Plateau (Kobayashi 1987, 1989). *Brachiaria ramosa* and *Setaria pumila* were so called tertiary crops because they were secondary crops to other millet species domesticated from their relative weeds in upland fields. On the other hand, *Digitaria cruciata* has been recently derived from the relative weed grown in maize or vegetable fields, Kashi Hill, Meghalaya, and is limited to the same area (Singh and Arora 1972). Tentatively, Indian millet species were domesticated in the process of diffusion from humid paddy fields in Eastern India to dry upland rice fields in the Deccan Plateau, Southern India.

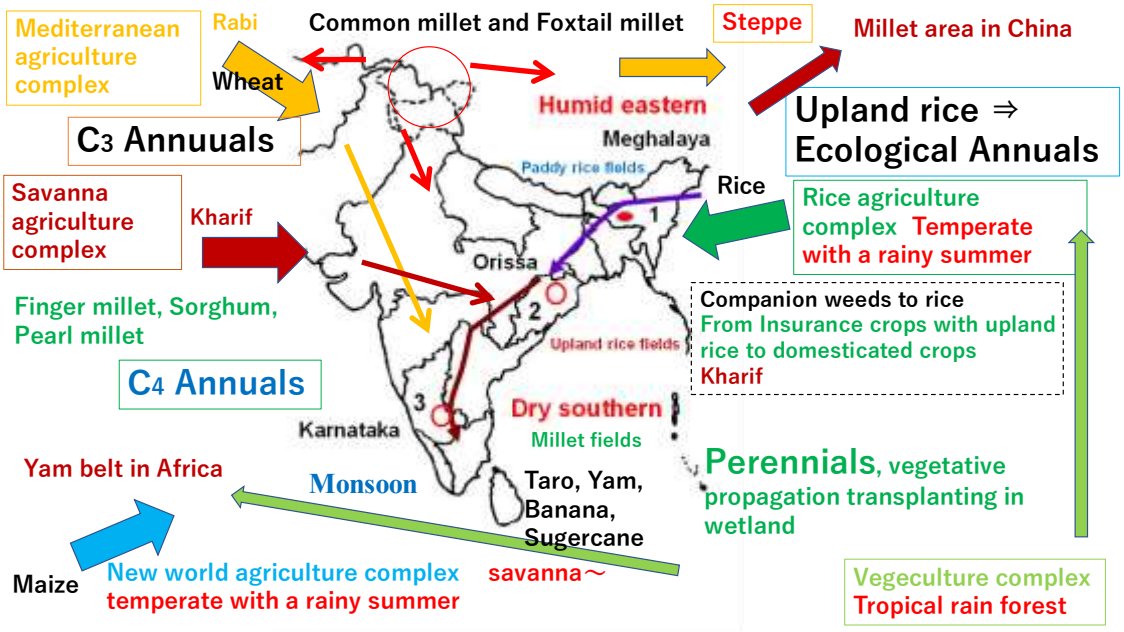
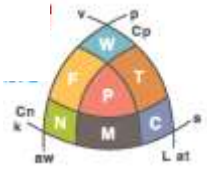


Figure 101. A new model of domestication process and dispersal of crops around The Indian subcontinent

Chapter 8. Biological diversity and Learning environment under the Anthropocene



Today in the Anthropocene, we are living under severe natural and artificial condition. These are the dramatic climate change, many natural disasters, infectious diseases by the vast populations of human being and livestock, and moreover Information Technology AI (artificial intelligence), many states of war and conflicts, etc. Those situations are sure to go serious hungry around the world.

Traditional culture on the basic agricultural complex in India, which will hope not to change for the future

I had been to the Indian subcontinent many times for the field works on millet during 1983 and 2001. I had visit over hundred farmers in so many rural villages. Farmers do not so much grow maize in Deccan Platou of South India and hill/mountain regions of East and West Ghats even today, because these areas were not fertile and furthermore little rain. The people do not like the taste of *mudde* made from maize flour, but they sometimes cook *upma*, *roti* and *vada*. In Pakistan, Nepal, and the millet cultivation areas of Africa, already, maize is a main grain and produced in large quantities, then this crop is taken in the traditional cooking style (Kimata 1990).

Maybe the intention is the same Ganji' s spirit as a spinning wheel, which has maintained food tradition and resisted against a new trend. In 1983 of my first visit to India, Many Taxi were tattered Ambassador cars and autorickshaws in New Delhi. The Lord Krishna's talisman was pasted on the broken speedometer, the door knob was come off when I pulled it. The headlamp of a few taxis did not lighten. On the contrary, people had driven many used cars of Japanese Datsun in Pakistan and Nepal.

Since 1968, the production of wheat, maize and rice were increased by the monoculture of Green Evolution, while the millet production has been decreasing. It means that the biodiversity of domesticated plants declines and numerous genes are lost. Under these situations, it will be afraid that the domesticated plants will become difficult to deal with the new regional/global environmental changes. Moreover, The diverse culture of daily life, local foods and traditional knowledge on nature may be lost, which farmers have inherited.

Then I have found out the difference between farming and agriculture (Table 54). The farming was a subsistence for family, and farmers had grown daily foods. They had cultivated low volume of many varieties of crops. There was high biocultural diversity in local community. Local farmers have high self-esteem. On the other hand, agriculture was an industry for state tax, strategic materials, and agricultural products. Famers conduct mass production of specific variety on major crops. Thus, biocultural diversity is low and declines (Shiva 1992, 1993).

Table 54. Comparison between farming and agriculture

	Farming	Agriculture
economy	subsistence, livelihood	industry, heavy investment of capital
cultivation area	small scale	large scale
worker	family	family, sharecropper, seasonal worker
produce	daily food	taxes, commodities, strategic materials, biofuels
crops	high-mix, low-volume production	mass production of specific crops
cultivation method	organic	inorganic, use of pesticides and fertilizers
biocultural diversity	high	standardization, low
basic agricultural complex	inheritance of will	decline or none
social form	local community	national government
self-esteem, pride	autonomy, independence	other power heteronomy, progression of self-domestication

The large-scale agriculture is operated by large farmers and companies for making money or trading materials in the world (Table 55). A few varieties of major crops are adopted in monoculture system for mass production, consumption and discard, then biocultural diversity has decreased in the plantation. On the contrary, a small-scale farming has been practiced on the home garden mainly for family and local community.

Table 55. Comparison between large-scale agriculture and small-scale farming

Large scale agriculture	Small scale farming
Plantation	Home garden
Large company for making money	Family to live
Industry/trade goods	Subsistence/self-sufficient food
Main crops/a few variety/monoculture	Diverse crops/many varieties/multiculture
Mass production/consumption/discard	Small quantity production/eat carefully/circulate
Decline of biocultural diversity/hard to sustain	Conservation of biocultural diversity/high sustainability

In comparison with the Japanese life style at the rural villages, the Indian farmers have cherished really their traditional life style (Table 56). We hope to continue diligently the Indian traditional and moderate rural community. However, because the population had increased rapidly in India after Green Evolution, now over 1.4 billion, the large-scale agriculture has been required for mass production by the American agricultural systems. In order to improve a bad social situation mentioned below, some villagers and city dwellers promote home garden, community gardens, edible ways, etc. in United Kingdom and Japan (Figure 102). Moreover, Organic farmers have their affiliated families with the citizen supported agriculture in the suburbs of city sides. The commercialism is overwhelmed, but the subsistence is very important even now.

Table 56. Comparison between rural village in India and rural village/suburbs in Japan

Rural villages in India	Rural village and suburbs in Japan
身土不二/one's birth are inseparable	身土分離/separation of body and soil
Circular farming/comply with the environment	Monoculture/not environmental friendly
mostly Subsistence	Primary industry
Simple living	Convenient life
Sustainable rural society	Unsustainable urban society
Adaptable to the period in valley of wind 風の谷	**Against the revelation**
Deteriorating environment	Loss of traditional culture
Resource depletion	Massive import of resourcess
Population increase	Declining birthrate and aging population
	High suicide rate

Community garden is important facility in the urban area (Figure 102). Here is a warm place for relating with neighbors of local community. Also, school gardens have an important role and multiple benefits for improving nutrition and education for children and their families (Hunter et al. ed. 2020). School garden programmes have been a popular development intervention for many decades. In the developing world, these have included teaching improved farming skills, supporting community food production, raising funds, and demonstrating exemplary agricultural practices to communities surrounding the schools. In the industrialized world, school gardens have served a broader educational function, helping children understand science, nature, and the environment. Increasingly a case is also made for reconnecting rapidly urbanizing school communities with the realities of rural areas, local food culture, local food biodiversity, and farm tourism. There is now a wider recognition of the role of school gardens in environmental and nature education, in local food biodiversity and conservation, food and ecoliteracy, diets, nutrition and health, and agricultural education. In the last century, in Europe and the United States, school gardens have featured as a hunger intervention. Some of the earliest gardening efforts remain useful reminders of school gardens and the role they played in hunger mitigation. In recent years, the Food Crops movement has grown, supporting school and community garden efforts. Learning about gardening, the environment, nature, and sustainable diets characterizes current school gardening efforts in Europe, Australia, and the United States (Gonsalves 2020, ed. by Hunter et al.).

The first Edible Schoolyard was established in 1995 at a public middle school in Berkeley. Here, almost 25 years after, the Edible Schoolyard has provided capacity building to teachers, administrators, nutritionists, food service staff, parents, and community leaders from more than 367 schools worldwide. Moreover, the project facilitates the Edible Schoolyard network including 5,513 school garden programmes located all over the world. Under the concept of Edible Education, the idea is to use food as a tool to teach lessons of the academic curriculum (https://edibleschoolyard.org/). There are many other good practices, for example, Crop Museums in Philippines, School Gardens in Australia, Burkina Faso and India, Edible Schoolyards in Scotland and the United States, etc.

How exactly is pupil mental health and well-being implicated in the practice of outdoor learning

and gardening? And how might we be able to design curricula that enhance and empower young people's ecological mindset and confidence? To answer these questions, we are working with school counsellors, teachers, and students of all ages to build therapeutic garden spaces (School of Geographical and Earth Sciences, The University of Glasgow).

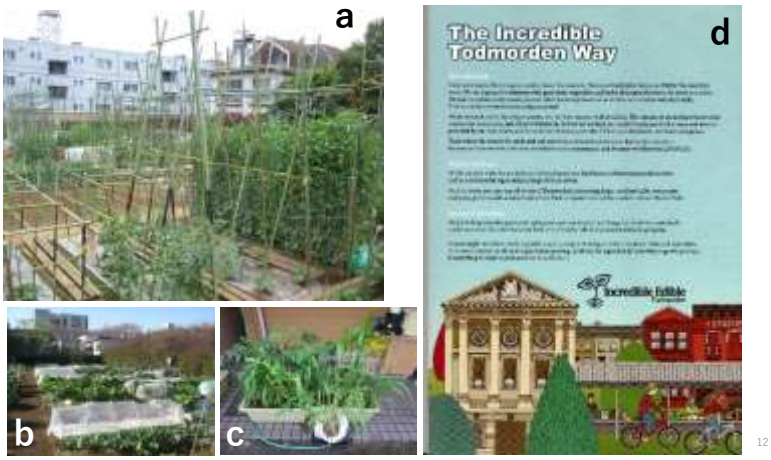


Figure 102. Community garden and edible way

a・b, community garden; c, edible way in Koganei, Tokyo; d, edible ways in Todmorden, UK.

The beginning of Anthropocene

The Anthropocene, Quaternary had started by the Trinity test of nuclear (1945) and immediately these atomic bombs had been dropped on Hiroshima and Nagasaki, Japan in the end of World War II (Table 57). The nuclear technology has developed, at the same time, the proliferation of nuclear materials has followed such as Chernobyl nuclear power plant accidents. Fukushima Nuclear Power Plant had melted down by Great East Japan Earthquake in 2011.

The Anthropocene appears in scientific and social discourse, especially with respect to accelerating geophysical and biochemical changes. Despite its rejection as a formal unit of Geologic Time Scale, Anthropocene will nevertheless continue to be used not only by Earth and environmental scientists, but also by social scientists, politicians and economists, as well as by the public at large (Wikipedia 200225.10.29).

Moreover, after the World War II, human had consumed the amount of fossil fuel. Moreover, big social changes have generated continuously, that is, the information technology/communication, the environmental change, pandemic and so on. The Information Technology and Communication has developed very fast from the broadcast by television (1953), Internet popularization (1986), SNS popularization (2004), via Artificial Intelligence, to Chat GPT (2023).

Our human beings have to consider the workaround of numerous natural disasters for maintaining our daily lives near the future. For example, there are typhoons, earthquakes, eruption etc. We have experienced many artificial disasters, environmental pollutions, *Kogai*, famines, wildfires of forests, microplastics, organic fluorine compounds, microplastic, etc. The human population had subsequently over 8.3 billion (2025.10.29). According to population explosion of human and livestock, they have begun to acquire many kinds of infectious diseases, influenza,

Coronavirus, bird influence, swine fever and so on. After Green Revolution, the science technology has progressed to genetic modification, completed human genome, genome editing, etc.

Anthropocene may be chaotic Kali Yuga of Hinduism. However, we wish to discover the Hope in the near future.

Table 57. Social changes over Anthropocene

A.D.	UN Declaration and International treaty	Nuclear power	Information and Communication	Environmental change		Pandemic of infectious disease
				Artificial disasters	Natural disasters	
1943				Bengal famine		
1945		Trinity test, Atomic bomb dropped on Hiroshima and Nagasaki		World War II, and then incleased usage of fossil fuel	Makurazaki typhoon	Population explosion
1948	Universal Deckaration of Human Rights			Expansion of Afforestation	Earthquakes in Fukui and Turkmenistan	
1953			Start of broadcast by TV	Increase rapidly the emission of CO_2, in 50's		Inclease in livestock numbers in 50's
1954		Bikini Atoll hydorogen bomb test, Radiation exposure of Daigo Fukuryu Maru		Inclease in new chemicals	Climate change	
1956				Minamata disease, Yokkaichi asthma (～1970's)		Asian influenza (1957)
1959				Itai-itai disease (1910～1970's), The Great Chinese Famine	Isewan typhoon	
1963		Power generation of Power test reactor/JPDR		Pollinosis (1961)		
1968				Green Revolution		Hong Kong influenza
1970	Treaty on the Non-Proliferation of Neclear Weapons				Cyclone to Bangladesh	
1972	Human Environment Declaration	Termination of Vietnam War				
1976					China/Tangshan earthquake	
1979		Three Mile Island Nuclear Power Plant accident		Genetic modification (1980's)		Acquired immunodeeficiency syndrome
1986		Chernobyl Nuclear Power Plant accident	Internet popularization			Bovine Spoongiform Encephalopathy
1993	Convention on Biological Diversity			Sick building syndrome (1990's)		
1995					Great Hanshin-Awaji Earthquake	
1999					Orissa super cyrlone	
2001					Gujarat Earthquake	
2003				Completed Human Genome		
2004			SNS popularization		Indian Ocean earthquake and tumami	
2005				Genome editing		Avian influenza
2006				Peak oil		
2007	Declaration on the Rights of Indigenous Peoples					
2008					Cyclone to Myanmar	
2009						Swine influenza
2010	UN Decade on Biodiversity				Haiti Earthquake	
2011		Meltdown at Fukushima Nuclear Power Plant		Spread of radioactive materials	Great East Japan Earthquake, Tsunami	
2014					Eruption of Mt. Ontake	
2015					Typhoon 18 heavy rain	
2016	UN Decade of Action on Nutrition					
2017	Treaty on the Prohibition on Nuuclear Weapons			CRISPR system		
2018	Declaration oon the Rights of Peasants					
2019	UN Decade of Family Farming					Coronavirus acute respiratory disease (2019～2023)
2020			Artificial Intelligence AI, Big data analysis			
2021	UN Decade of Biodiversity					
2022		War of aggression to Ukraine by Russia				Bird Influenza
2023	International Year of Millets	Marine drainage of contaminated treated water at Fukusgima	ChatGPT	Organic fluorine compounds, micro plastic	Moorocco Earthquake, Libya flood, Forest fire	Swine fever
2024		Israel Invasion on Gaza			Noto Peninsula Earthquake	
2025				Wildfire		

Definition regarding the domestication of plants and animals, and the self-domestication of humanity

First of all, we need to define the concept “domestication.” The domestication process has considered specifically in the case studies mentioned above chapters. Here the definition on the domestication of plants and animals was presented in Table 58.

Because our ancestor of human had not been existent in Tertiary, the biological evolution of wild species had been under the control of natural selection. Since the Anthropogenesis in the Pleistocene, Quaternary, the artificial selection by human had added to the harsh natural selection. Then, the cultural evolution had progressed under the unsparing Nature. While receiving the strong artificial selection pressure, the human being and the domesticated plants had coexisted by their symbiotic evolution. However, the plants had been able to escape from human action by natural hybridization with the relative wild spices or weed.

It is the definition that under the self-domestication process, very severe artificial selection has the profound effects among each human lived in urban societies where have lost touch with nature: degeneration as a living thing; feeding, substitution of AI for self-thinking; convenience by overuse of energy and machinery. Adapting to the Anthropocene, the subordinate evolution was prompted under the hyper-domestication process. Investigators have initiated the artificial genetic changes and then they had produced unnatural foods.

Table 58. Definition regarding the domestication of plants and animals, and self-domestication of humanity

Geographical period	Era and evolutionary style	Characteristics
Tertiary	biological evolution	wild species under natural selection
Quaternary/Pleistocene	2,580,000 years ago	Anthropogenesis
semi-domestication process	cultural evolution	under harsh natural selection in addition to human artificial selection
Quaternary/Holocene	11,700 years ago	
domestication process	symbiotic evolution	by the strong artificial selection pressure on domesticated plants, and human preservation, the natural selection had become inapparent. However, the plants had been able to escape from human action.
Quaternary/Anthropocene	from 1945	
hyper-domestication process	subordinate evolution	Investigators have initiated the artificial genetic changes and then they had produced unnatural foods.
self-domestication by human itself	regressive evolution	Very severe artificial selection has the profound effects among each human lived in urban societies where have lost touch with nature. Degeneration as a living thing: feeding, substitution of AI for self-thinking, convenience by overuse of energy and machinery.

At the present time, the most important issue is the self-domestication of humanity in Anthropocene. The several properties on the self-domestication of humanity are listed in Table 59. We defined that the concept “self-domestication” was as follows. Our humanity is creator and also torchbearer of culture. They put themselves in their cultural environment. On the case of human self-domestication, they had not been domesticated by the other species, but they had been done by themselves.

Tables 58 and 59 were referred through many authors (Yamamoto et al 2009, Obara 1995,

Parson 2020, Kumashiro 2024, Harari 2015, Kumashiro 2024, etc.).

Relationship between the genesis of city-state, polis and grains

The polis state power had been incubated by the tax of grains since thousands of years after the domestication of cereals. The novel hypothesis on the origin of state was proposed by Scott (2009, 2017). The following points are summarized it. Zomia is vast hill area from Central Plateau of Vietnam to North East of India, where is very interested in the relations between state formations and ecological diversity. Moreover, the one hundred million of many ethnic minorities have lived here. The part of them does not necessarily belong to any states, because they have gotten away from the states.

Sedantism and the first appearance of towns were typically seen to be the effect of irrigation and states. Sedantism and civilization led directly to state formation, yet states pop up only long after fixed-field agriculture appears. Only the cereal grains can serve as a basis for taxation: visible, divisible, assessable, storable, transportable, and "rationable." Other crops – legumes, tubers, and starch plants – have some of these desirable state – adapted qualities, but none has all of these advantages.

Grain hypothesis: It is surely striking that virtually all classical states were based on grains, including wheats, millets and rice. History records no cassava states, no sago, yam, taro, plantain, breadfruit, or sweet potato states. State formation becomes possible only when there are few alternatives to a diet dominated by domesticated grains. Neolithic villages generally occur in water-rich areas and subsist largely by hunting and foraging though there is evidence – disputed – of cereal horticulture and livestock rearing. The earliest large fixed settlements sprang up in wetlands, not arid settings; they relied overwhelmingly on wetland resources, not grain, for their subsistence; and they bad no need of irrigation in the generally understood sense of the term.

And in this case, population concentration must be distinguished from state making; wetlands abundance, as we have seen, could lead to incipient urbanism and commerce, but did not lead to state formation without grain growing on a large scale. The key to nexus between grains can grains and states lies in the fact that only the cereal grains can serve as a basis for taxation: visible, divisible, assessable, storable, transportable, and "rationable". Other crops – legumes, tubers, and starch plants – have some of these desirable state-adapted qualities, but none has all of these advantages. To appreciate the unique advantages of the cereal grains, it helps to place yourself in the sandals of an ancient tax-collection official interested, above all, in the case and efficiency of appropriation.

The sifting cultivation or slash-and-burn cultivation was supported by the biodiversity, that is, so many traditional varieties of root vegetables and tubers. This farming system have been hated by the states because of no taxation. Therefore, it has been said that the mountain people were savage, while the flat land dwellers were civilized in rice-growing nation. In the mountain area, the infectious disease has not been many, because of few mosquitos. These escape farming was supported by the rescue foods, such as taro, yam, sago palm, and then recently cassava, maize, sweet potato, etc. In this way, mountain people have selected to live freely.

We, as a species, are inclined to see ourselves as the agent in narratives of domestication (Table 59). We domesticated wheat, rice, the sheep, the pig, the goat. But if we squint at the matter from a slightly different angle, one could argue that it is we who have been domesticated.

Table 59. Several properties on the self-domestication of humanity

Self-domestication	Definition	Our humanity are creator and also torchbearer of culture. They put in their cultural environment. On the case of human self-domestication, they had not been domesticated by the other species, but they had been done by themselves.
Evolution of friendliness	Optimism	*Homo sapience* had acquired the friendliness to the same species and the other species by natural selection, and then they had been able to prospere, in spite of the other extinction.
Dietary life of hunter-gatherers	A case of integrated mind; Think experientially by oneself	A case study on Hadza in Tanzania: Everyday they go look for foods, return to their camp site, and cook/eat/sleep with their family. The ape dose not taking food home at their lair.
Dietary life of city people	A case of self-domesticated mind; depended on the external information device	The city dwellers purchase micro wave foods at spermarket, they cook food unusually. They eat meal usually alone at dining room and cafeteria.
Prejudice	discrimination	negative emotions against a population.
Evil forces	A pessimistic view, genocide	When the human feel threat, they can be ignored against the different group. The rules and norm for treating humanely are not appilicable.
Self-domestication syndrome of animals	distinguish between human and animals	Domesticated annimals become obedient as a result of genetic adaptation. The process of reactive aggression is called a self-domestication.

Hare & Woods (2020), Kimata (2012), Mithn 1996, Omoto ed. (2002), Wranganer (2019) cited.

Millet production under the wars and disasters (2019)

Shiva (1991) had pointed out her foresight which this regressive evolution had worked already involving some concept on self-domestication. The main threat to living with diversity comes from the habit of thinking in terms of monocultures; from what Shiva (1991) had called “Monocultures of the Mind.” These make diversity disappear from perception, and consequently from the world. The disappearance of alternatives gives rise to the TINA (there is no alternative) syndrome. How often in contemporary times total uprooting of nature, technology, communities and entire civilisation is justified on the grounds that ‘there is no alternative.’ Alternative exit, but are excluded. Their inclusion requires a context of diversity. Shifting to diversity as a mode of thought, a context of action, allows multiple choices to emerge.

Protecting native seeds is more than conservation of raw material for the biotechnology industry. The diverse seeds now being pushed to extinction carry within them seeds of other ways of thinking about nature, and other ways of producing for our needs. The native seed becomes a system of resistance against monocultures and monopoly right. Diversity as a way of thought and a way of life is what is needed to go beyond the impoverished monocultures of the mind.

Over and above rendering local knowledge invisible by declaring it non-existent or illegitimate, the dominant system also makes alternatives disappear by erasing and destroying the reality which they attempt to represent. The fragmented linearity of the dominant knowledge disrupts the integrations between systems. Dominant scientific knowledge thus breeds a monoculture of the mind by making space for local alternatives disappear, very much like monocultures of introduced plant varieties leading to the displacement and destruction of local diversity.

What have usually been called marginal crops or coarse grains, are nature’s most productive

crops in terms of nutrition. That is why women in Garhwal continue to cultivate *mandua* (finger millet) and women in Karnataka cultivate *ragi* (finger millet) in spite of all attempts by state policy to shift to cash crops and commercial foodgrains, to which all financial incentives of agricultural development are tied. A woman in a Himalaya village once told me, 'Without our *mandua* and *jhangora* (Indian barnyard millet), we could not labour as we do. These grains are our source of health and strength.'

There is an intimate relationship between weeds and crop, especially in the tropics where weedy and cultivated varieties have genetically interacted over centuries and hybridize freely to produce new varieties.

This utility of farmers' and tribals' seeds has high social and ecological value, even if it has no market value attached to it. The limits of the market system in assigning value can hardly be a reason for denying value to farmers' seeds and nature's seeds (World Rainforest Movement 1991).

The reduction in availability of fertile land and genetic diversity of crops as a result oof the Green Revolution practices indicates that at the ecological level, the Green Revolution produced scarcity, not abundance. Green Revolution is the name given to this science-based transformation of Third World agriculture, and the Indian Panjab was its most celebrated success. Paradoxically, after two decades of the Green Revolution, Punjab is neither a land of prosperity, no peace.

The millets, called minor cereals occupied the largest area under cultivation in Punjab. The millets are so diverse, not because they are insignificant crops. *Kutki* (*Panicum miliare*, syn. *P. aumatrense*), *jawar* (*Sorghum vulgare*, syn. *S. bicolor*), *mandal* or *chalodra* (*Eleusine coracana*) and *bajra* or bulrush millet (*Pennisetum typhoidenam*, syn. *P. americanum*) were the main millets cultivated in Punjab, covering 43% of the area. Besides these, there uncultivated or wild varieties of millet like *shama* (*Panicum hydaspicum*), *Cenchrus echinatus*, *Pennisetum cenchroides*. In addition to these, the more well-known cereals were *makki* or maize and wheat.

As a result of the Green Evolution in Panjab, common lands under forests and pastures have been put under agricultural crops. AS the Green Revolution spread, local community management broke down and grazing lands and forests were broken up for monoculture cultivation.

Swaminathan (2022) had written the following about two major paradoxes of global food systems: the persistence of hunger in the midst of an impressive technological capacity to grow more food; and the narrowing of crops diversity within global food systems in the face of a fast-grow world population. The yields of major crops are reaching a plateau that may not be easy to overcome. More innovative solutions are needed to address the yield bottleneck. Leveraging agro-biodiversity to grow more and diverse nutritious food in difficult areas with poor soil and challenging climatic conditions should receive greater attention. This is not new to us, since risk-aversion practices have always guided generations of farmers who have been growing different crop and varietal mixes to buffer against shocks. Farming families have often been motivated by a desire to minimize risk, not just maximize profits; hence, the wisdom underlying the decisions to balance subsistence and market motivations needs to be recovered.

A case study in the wartimes of Japan

The cultivation area of millets had increased in the wartimes of Japan. The government had

encouraged to grow millets by many booklets for enduring hunger in the wartimes. The booklets were printed on the day before dropping the first atomic bomb on Hiroshima, and then Nagasaki. The Anthropocene has started after Hiroshima followed on Trinity Nuclear Test.

The millet production of modern Japan was shown in Table 60 and Figure 103. The total production was about 350,000 ha (cho 町≒ha) in 1900's. After that the millet production have gradually decreased without the wartimes, and then it is a trace in 2023.

Table 60. Millet Production in Japan

Millet	1900	1950	1990	2001	2002	2003	2023
Foxtail millet	243,700	66,100	44	50	53	44	
Common millet	34,100	26,200	146	169	152	121	
Japanese barnyard millet	71,900	33,200	290	110	150	156	
Sorghum	The Russo-Japanese war (1904)					22	
Job' tear				344	312	358	
Finger millet	World War I (1914~1918)/II (1939~1945)					trace	
Total	349,700	125,500	480	673	667	701	251
Buckwheat				41,800	41,400	43,500	35,500
Tartary buckwheat						14	
Amaranth				15	11	18	

農産業振興奨励会2001～2003、**新需要穀類等生産・流通体制確立事業実績報告書**

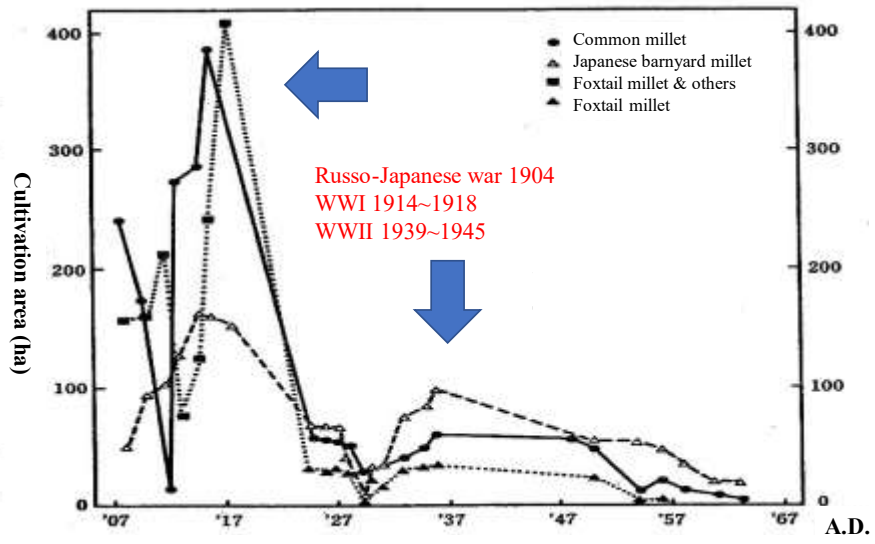


Figure 103. World war I/II and Cultivation area of millets in Japan.
Books on Japanese barnyard millets and traditional foods in war time.

For instance, a farmer has prepared the food grains of foxtail millet and upland rice in the storehouse for famine (Figure 104). Another old farmer has still cultivated many local varieties of millets for conservation of their seeds today. These villages were very famous, because the area was noted specially for their villagers' longevity and health. The exemplary farmers have still held local varieties of millets and their excellent practices on farming. Many researchers have visited these

villages in this area of Kanto mountains, Central Japan. We have held the exhibitions of millet cultural complex in many places.

Figure104. A storehouse of a farmer for food security at Fujino, Kanagawa, Japan
a, storehouse; b, the inside; c・d, local variety of foxtail millet; e, a local variety of non-waxy upland rice; f, waxy rice variety.

Great East Japan Earthquake had attacked North East Japan on March 11, 2011 (Figure 105a, b). The most paddy fields had washed away by the repeating waves of big tsunami in the coastal area. However, the upland field had not washed away, because the waves had unreached to hill area. Therefore, local famers had reaped their harvest of millets and other crops (Figure 105c, d).

Figure 105. Landscapes of seaside and hillside after Great East Japan Earthquake
a, paddy fields washed away; b, overgrowth of weeds; c, no damage of millet field on hillside; d, the harvest.

Conservation of biological diversity for our seeds and foods

Against the recent trend, we have hold preserved many local varieties of millets and traditional crops for decades. We had exhibited our projects by Working Group for People and Seeds for the Future, Japan Civic Network for CBD at the Conference of the Parties; CBD/COP10, Nagoya 2010 (Figure 106).

Conference of the Parties; CBD/COP10
Nagoya 2010
Japan Civic Network for CBD
Working Group for People and Seeds for the Future: exhibition booth/ Booklet/Position paper

Figure106. Conference of the Parties; CBD/COP10, Nagoya 2010

These local varieties of crop seeds have the social common capital, which have belonged to

local farmers and communities. After the Great East Japan Earthquake on March 11, 2011, I had transferred our millet accessions (c.a. 10,000 accessions of seed samples) to Millennium Seed Bank, Royal Botanic Gardens Kew (Figure 107), because we had to prevent them immediately from the scheduled blackout and radioactive rays (expedited on June 22, 2011).

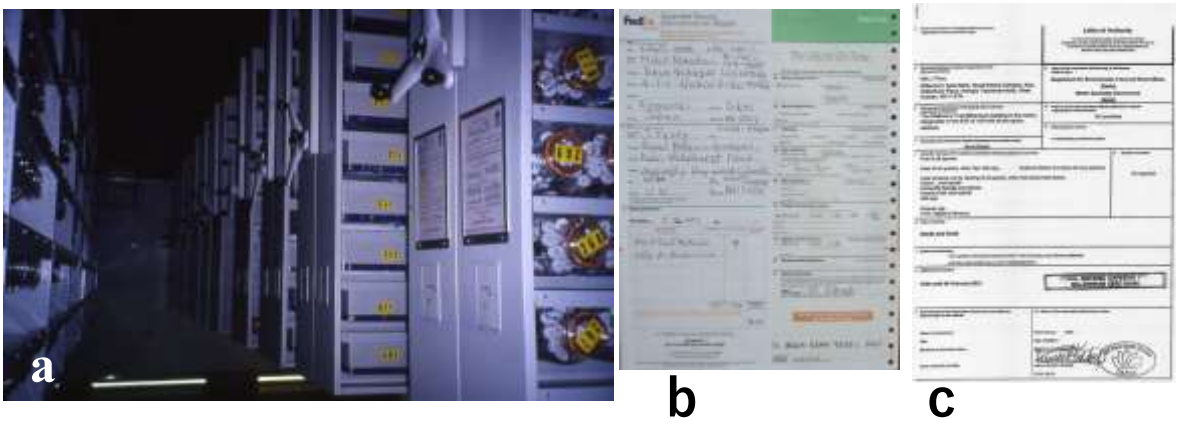


Figure 107. Millenium Seed Bank of Ryal Botanic Garden

a, storage room; b, FedEx cover letter in June 22, 2011; c, acceptance certificate.

We have experienced the social phenomena on droughts, wars and famines many times in the 20th century (Table 61). For example, in India, there were three times of severe widespread hungers, that is, the drought of maximum 3,250,000 deaths in 1900, Bengal famine of maximum 3,500,000 deaths in 1943, and the drought of maximum 1,500,000 in 1965.

Total population of the world is over eight billion. Total production of grains was about 3.9 billion tones. Millets and others were cultivated in 137 nations in 2021. The percentage of production were 9.7%. Millets and others were eaten by over 0.7 billion people in Afro-Eurasia. On the other side, the population of Japan was 1.6% in the world, while the grain production was only 0.3% in 2021. Japan must produce more grains for food security. We distribute millet seeds to citizen for their family farming.

Table 61. Drought, War and Famine in the 20th century

Common Era	Area	Cause	Number of starvation deaths
1900	India	drought	250,000~3,250,000
1918	Germany	World War I, bad harvest, Turnips in Winter (1916~1917)	762,000
1918	World	war dead	8,529,000
1921	Russia	drought	5,000,000
1928	North China	drought	3,000,000
1932	Ukraine	Holodomor, policy of USSR	2,600,000~10,000,000
1932	Kazakhstan	interlocking Holodomor	1,200,000~1,500,000
1936	China	drought	5,000,000
1941	Russia	besiegement by German army	1,000,000
1941	Greek	occupation by German army	300,000
1942	China	Henan famine, invasion by Japanese army	2,000,000~3,000,000
1943	India	Bengal famine	1,500,000~3,500,000
1944	Netherlands	World War II, Famine winter	22,000
1944	USSR	Siege of Leningrad	1,000,000~1,500,000
1945	World	World War II	20,000,000
1945	World	war dead	19,500,000
1947	USSR	bad harvest, restrictions on annexed land	1,000,000~1,500,000
1947	China	Great Leap Forward policy	36,000,000
1965	India	drought	1,500,000
1968	Sahel	drought	1,000,000
1975	Cambodia	policy of Khmer Rouge	2,000,000
1996	North Korea	flood damage, Arduous March	220,000~3,500,000
1998	Congo	civil war	3,800,000
2020~2021	World	Coronavirus deaths	15,900,000
	Japan		
1732	Kyoho	bad harvest, locust invasion	1,000,000
1782	Tenmei	bad harvest	1,100,000
1833	Tenpo	bad harvest	300,000
1930	North-East	bad harvest	not clear
1945	domestic and overseas	World War II, invasion by Japanese army	850,000~1,400,000
1945	Japan	war dead (including the above)	3,100,000
1946	domestic	bad harvest, after the defeat in war	not clear
1993	North-East	bad harvest	0
2011	North-East	Great East Japan Earthquake	22,228

After the Green Evolution, the grain production has been concentrated on three major cereals, which are high yield varieties of wheat, maze and rice. These are important as the export products. The cultivation area of other cereals has been significantly decreased. However, we can recognise the production of the other cereals, for example, rye, oat, sorghum, millet, buckwheat and so on for our subsistence and family life in the war time of Ukraine. On the contrary, Japan keeps only rice production anyway, but the other cereals are cultivated only trace (Table 62). Majority of Japanese inhabit in urban area, they do not involve in their subsistence, and they buy imported foods. They have forgotten the hunger in wartimes or disasters.

The productions of millets and sorghum have increased in many nations as shown in Table 63 (FAOSTAT 2022). Millets are nutritious grains which are able to grow under the harsh environment. FAO had held the International Year of Millets in 2023 in order to re-evaluation those orphan crops. Especially in India and African nations, the production of millets and sorghum are increasing. It is of high interesting that the production of sorghum is increasing in USA, Mexico and Brazil.

Common millet is continued to grow in many places throughout the Eurasia (Figure 108). We purchased them at the markets in European countries.

Table 62. Compare of crop production between Ukraine and Japan.

Cereals	Ukraine		Japan	
	Nation area ㎢	Population	Nation area ㎢	Population
	604,000	43,734,000	378,000	126,47,6000
	Cultivation area ／ha	Production ／tone	Cultivation area ／ha	Production ／tone
Winter				
Wheat	6,564,500	249,123,500	212,600	949,300
Barley	2,374,500	7,636,340	63,600	221,700
Rye	137,800	456,780		
Ort	199,000	510,000	165	317
Summer				
Maize	5,392,100	30,290,340	62	164
Rice	11,200	60,680	1,462,000	9,706,250
Sorghum	47,200	106,560		
Millet	159,100	256,050	295	247
Buckwhwat	84,100	97,640	66,600	44,800
Soy bean	1,364,300	2,797,670	141,700	218,900
Sunflower	6,480,900	13,110,430		

FAOSTAT(2020)

* Common millet in Ukuline

** Japanese barnyard millet, foxtail millet, common millet

Table 63. Productions of millets and sorghum (FAOSTAT 2022)

Nation	Millets		Nation	Sorghum	
	Area/ha	Production/tone		Area/ha	Production/tone
India	8488150	11849190	**Sudan**	7000000	5248000
Niger	6780623	3656958	**Nigeria**	5700000	6806370
Sudan	2500000	1675000	**India**	3800810	4150570
Mali	2104437	1844664	**Niger**	3786257	2100697
Nigeria	2000000	1941220	**Burkina Faso**	1958672	2013869
Chad	1194064	694196	**USA**	1849430	4769960
Burkina Faso	1043257	907745	**Ethiopia**	1660000	4200000
Senegal	969693	1097033	**Mali**	1639394	1603394
China	900310	2700495	**Mexico**	1332929	4754169
Ethiopia	455000	1150000	**Brazil**	1043480	2923318
Japan	285	251	**Japan**	0/trace	0/trace

Figure 108. Sale of millets at the super market in Europe

Learning Environment Framework based on ethnobotanical Aspect

During the Anthropocene, *Homo sapiens* have deviated from nature. The majority in urban areas and most of them are office workers. They do not have many subsistence experiences, such as gathering, hunting, fishing, or farming. Consequently, they have failed to develop wholesomely the structure and function of their minds under historical situations.

The structure of the mind consists of five intelligences, as shown in Figure 110 (natural history, technical, social, general, and linguistic), and its function consists of seven senses as illustrate in Figure 111, [eyesight, hearing, taste, smell, touch, the sixth sense (intuition), and the seventh sense (conscience)]. These five intelligences and seven senses are developed in a learning environment. We propose a model for the learning process in this environment. In the ten learning programs, an integration program Play is the beginning of learn.

Human cultural evolution rapidly developed using fire, tools, and language through the domestication process of plants and animals in the Holocene, Quaternary period. These phenomena depended on the cultural evolution of the human mind and then they became civilized. Today, convenient cities are being created in surplus. Urban people are fed artificial foods, and their thought are dependent on artificial intelligence added through big information technology.

This indicates that self-domestication of *Homo sapiens* has evolved over time. We do not grow grains or vegetables ourselves, but purchase them in markets and shops. In addition, we use convenient tools, such as smartphones and personal computers, and we do not think much about nature, subsistence, social lives, and so on. We must learn about the environment deeply to prevent excessive self-domestication. We need to rehabilitate and develop our minds through diverse experiences in nature and rural areas toward the civilization of living things.

A structure of the environment learning process for life ― For creating the fundamental theory of environment learning ―

The main purpose of environmental education in Japan is to deliver the information on global issues. Most specialists do not yet reach basic agreement on the systematic methodology of environmental education study. It is the fundamental theory of environment learning that everyone needs to learn the environment around them, to develop their aptitude and individual nature, and to live in comfort. The methodology of environmental education study has stayed mostly on the practical stage but does not advance highly to the theoretical stage.

Today, the modernized human being got away from the natural environment, promoted remarkably the cultural evolution, and then greatly developed the complex civilization by science and technology beyond their abilities. The capacities, which made up the “mind structure” of human being, rather lost the integrating function in accordance with their urbanization and development of computer programing language. It is a fundamental issue of environment that urban residents cannot learn nor do the environment from the nature and subsistence in rural areas. The modernized people need to acquire the scientific knowledge at schools, and experience the traditional knowledge at rural communities. They must learn the environment for recovering the integrating function and also nurture their world view for their fertile lives throughout their lifetime.

I propose working hypothesis, named “a Structure of the Environment Learning Process for Life,” as shown in Figure 109. This model is integrating the whole knowledge on subsistence,

science, their relationship, and intuition in an individual “mind structure.” It is desired to promote theoretical studies based on educational practices for designating a new subject “environment studies” in the school education as a result of the research meeting for environment studies curriculum. Moreover, it is necessary to construct “the Fundamental Theory of Environment Learning.”

Environmental education studies are clearly the integrated domain that involves numerous sub-domains, for example ecology, geography, anthropology, environmental sciences, pedagogy and so on. We need an integrating framework of environmental education programs to practice and research them. The Kaleidoscope system has proposed as a kind of framework on environmental education programs (teaching/learning) as illustrated in Figure 109 (Kimata 1990). The system consists of ten programs, that is, (1) basic programs: N, natural history; C, cultural history and W, world view; (2) relating programs: M, making; T, thinking and feeling; (3) integrating program: P, play; and (4) action programs: L, local, Co, cooperation and Con, conservation. We hope to reach effectively the goal (six objects) of environmental education through the system. The cooperation program has been one of action programs in the Kaleidoscope system. This cooperation program relates closely to the partnership networks. The partnership networks are very important to promote the environmental education for sustainable society now.

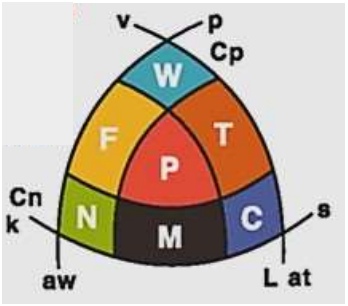


Figure 109. Environment Learning Framework (ELF)

N, nature; C, culture; W, world view: F, feeling; M, making; T, thinking;
P, playing. Cn, conservation; Cp, cooperation; L, local.
aw, awareness; k, knowledge; s, skill; at, attitude; p, participation; v, value.

Mithen (1996) has explicated the evolution of mind at our history as follows. It was during that time that the distinguishing features of the human mind arose, features such as language and an advanced intelligence. To gain an understanding of the mind leads on to an appreciation of what it means to be human. The onset of farming is frequently invoked as the turning point of prehistory. Without agriculture we would not have had towns, cities and state society. The rise of agriculture was a direct consequence of the type of thinking that evolved with the emergence of cognitive fluidity. More specifically, I will propose that there were four aspects of the change in nature of the mind which resulted in a reliance on domesticated plants and animals when environmental conditions abruptly altered 10,000 years ago.

Moreover, he has continued to explain the origin of agriculture and four aspects of change in the nature of mind. 1) The ability to develop tools which could be used intensively to harvest and process plant resources. This arose from an integration of technical and natural history intelligence. 2) The propensity to use animals and plants as the medium for acquiring social prestige and power.

This arose from an integration of social and natural history intelligence. 3) The propensity to develop social relationships with plants and animals, structurally similar to those developed with people. This is a further consequence of an integration of social and natural history intelligence. 4) The propensity to manipulate plant and animals, arising from an integration of technical and natural history intelligence. When people were faced with the cognitively fluid mind that made it possible for them to find a solution: the development of an agricultural lifestyle. Nevertheless, agriculture fundamentally changed the developmental contexts for young minds: for the vast majority of people alive today, the world of hunting and gathering, with its specialized cognitive domains of technical and natural history intelligence, have been left behind as no more than prehistory.

I have modified Mithen' s theory (1996) in Figure 110. The holistic humanity had acquired those integrated intelligences, but he was interrupted and collapsed his integrating intelligences under the self-domestication process on the modern civilization. The language has been transformed to the information, and then to the Artificial intelligence. No matter how civilized by the Artificial intelligence, we need the Natural Intelligences including the general intelligence in the future.

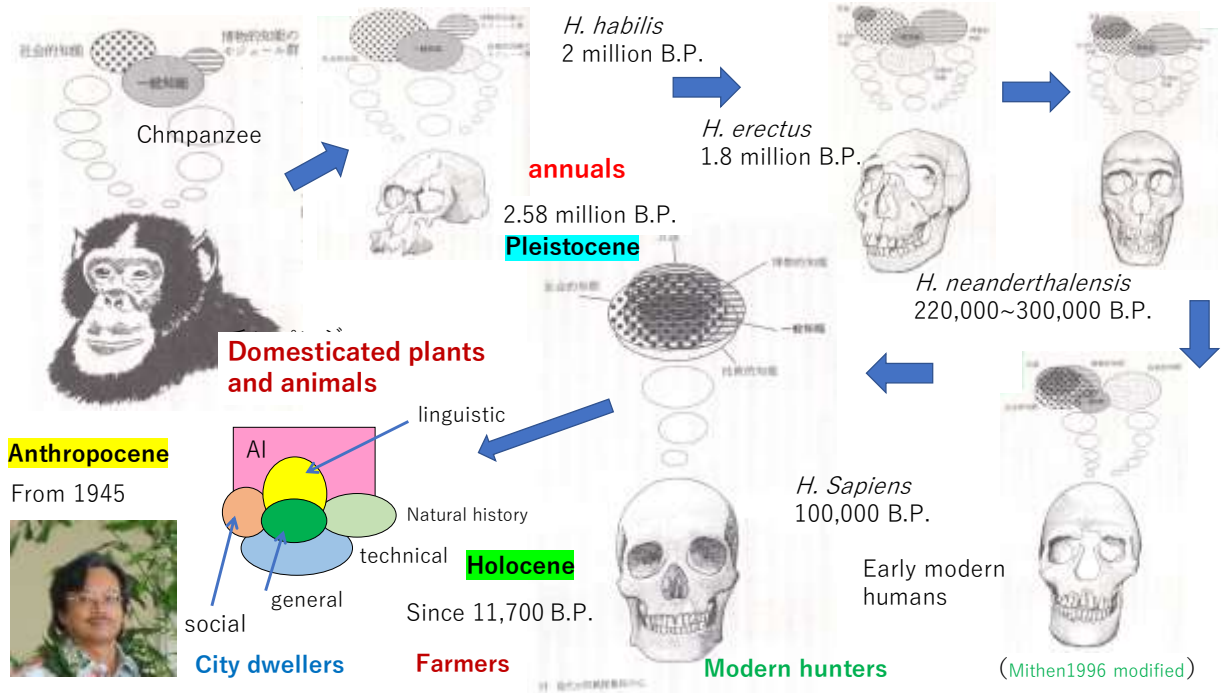


Figure 110. Evolution of mind in humanity during Quaternary transition

This framework had been inspired by "The Evolution of Mind in Prehistory" (Mithen 1996), "Human, Play and Nature" (Iwata 1986) and "the sociopath next door" (Stout 2005).

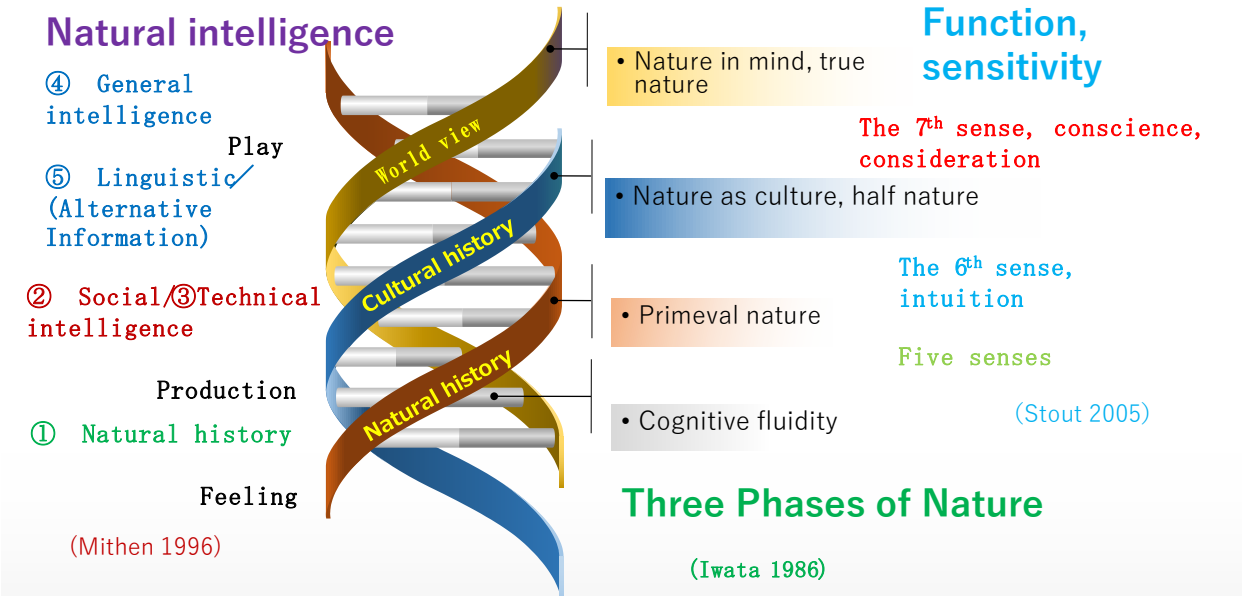


Figure 111. Auxiliary work model on the structure, function and cognitive fluidity

Case studies in Japan and the others

Most people take a great interest in global environmental issues such as the greenhouse effect, acid rain, deforestation, desertification, biodiversity erosion, population explosion and so on. They are very concerned not only about these serious global problems, but also about local problems such as drainage, garbage disposal, noise, food contamination and security, radioactive contamination and so forth in their daily life. Therefore, environmental education has become an object of attention, as it can play an important role in solving those problems. A principal aim of environmental education is to support the personal learning so as to hand on or re-create traditional knowledge appropriate to local natural conditions. Through environmental studies, the people gain the practical integrated knowledge and skills for conserving natural and cultural heritage without losing the comfort of their lives. Environmental education is an essential part of lifelong education.

The main cause of environmental issues is not to be able to learn environment and not to learn it. The goal of ENVIRONMENTAL EDUCATION/LEARNING is to inherit nature and culture, and to create a sustainable society. Environmental education studies are based on environmental studies which is a new integrated domain from a view point of holism. This domain is not located in natural and social sciences as an analytical domain. The six objects of environmental education have been given through the deepening international discussions (Belgrade Charter 1975). The contents of ENVIRONMENTAL EDUCATION/LEARNING are not only outdoor activities of nature observation and camping, separating activity of garbage etc., but also the aims are the formation of values based on learning scientific and traditional knowledge and the activities of environmental conservation and creation. For those reasons, we need to present whole structure of ENVIRONMENTAL EDUCATION/LEARNING and to position each program in the structure. Kimata (1990) proposed ELF (Environment Learning Framework) as a framework of ENVIRONMENTAL EDUCATION/LEARNING, which is educational methodology and practices for creating the sustainable society.

I. Philosophy on Environmental Education Studies and Teaching/Leaning Activities for Environmental Education ELF: N, C, W

1) What is environmental education? Searching an environmental education for sustainable society.
2) Three phases of nature and a framework of environmental education program
3) Short history of environmental education in Japan
4) A model of curriculum for environmental education
5) Teaching/learning activities for environmental education

II. Partnership Network and Policy for Environmental Education ELF: C, Co, L

Networks, partnership and linkages for sustainable society
Environmental education partnership network in the Asian-Pacific Region
Environmental education partnership network in Japan
Environmental education partnership network of Tokyo Gakugei University
A workshop for ODA in education

III. Ethnobotany of Traditional Agriculture and Rural Communities ELF: Cn, Co, C, N, M, L

Introduction
Means of rural communities as an environmental culture: millets, traditional knowledge and environmental conservation
A case study 1: coevolution of Indian millets between human beings and plants
A case study 2: NPO-Native Seeds/SEARCH in USA
Some issues in urban and rural communities
Exchange program through environmental education among people lived in city and village

IV. GLOBE Program Activities in Japan ELF: N, Cn, Co

Beginning and today
Goals of GLOBE Program

V. Millet Straß Promotion Association ELF: N, C, M, Cn, Co

Seminar
Cultivation training

1) Formation of Vernacular Names for Weeds and Plant Naming Programmes for the Re-creation of Children's Culture ELF: N, C, T

The formation of vernacular names was studied for the weed species of genus *Rorippa*, Cruciferae. The linguistic mode and meaning were compared among scientific, English, and Japanese standard and vernacular names. The scientific, English, and Japanese standard names were derived mainly from morphological and ecological traits and place-names, while the vernacular names were uniquely formed by local farmers. The result obtained for that study provided crucial insight for the plant naming programme discussed in this paper (Kimata et al. 20077).

The plant naming programme was designed and applied twice to the activities of Dokodemo Museum Eco-Project and Nukui Agriculture School for Boys and Girls in 2004. The study involved mainly children from primary schools. These activities required them to name a plant on their own after observing them and their habitats in the fields. The names given by the participants had the structure of {adjective word + root + supplementary word} or consisted of unique words without

any root. The root was mostly a word indicating a plant habit or organs such as herbs, flowers, seeds, leaves and so on. The adjective word often showed morphological, ecological, and sensuous traits or their composition. The supplementary word was rarely used when the participants hesitated to name a plant. At the same time, they drew sketches of plants and searched for further information in illustrated plant dictionaries. After checking, the Japanese standard and scientific names and reading comments, it is possible that they might have understood that their names for plants were fair and sensible.

First, children form vernacular names, then learn Japanese standard names and finally learn scientific names. This is a suitable way to learn about plants. In fact, it was a very interesting activity for the modern children to name a plant on their own because children exhibited such behavior as part of their own culture all across Japan about 60 years ago. This plant naming programmes may be effective in re-creating of children's culture which is have almost lost at the present time. Further, we need to develop a method to learn scientific names easily because they are common names across the world.

2) The environmental awareness and its transformation on biodiversity conservation and maintenance of university campus ELF: N, Co, L

There are many plant and animal species including tall trees grown up in the campus of Tokyo Gakugei University since 1946, when the campus facilities had moved to the present site in Koganei-shi, Tokyo. This campus is a splendid biotope networked with many other metropolitan parks and was named "Gakugeinomori," the grove of Gakugei University, recently. Gakugeinomori Environment Organization (GEO) put directly under the president of Tokyo Gakugei University as a consultative meeting which was consisted of students, faculty, staffs and neighboring residents. This organization has the obligations to publish the Annual Report on Environment, to discuss a comfortable campus environment and then to advise the staffs and students to improve the environment.

The attitude survey on the campus was carried out to the students, faculty, staffs and neighboring residents by GEO. As the statistical results including multivariate analysis and text mining, the most respondents had favorable impression to the campus and its name "Gakugeinomori," but they hardly knew the conservation activities by GEO. Particularly it was quite obvious that the students were shown less interest in natural environment of the campus than the other attributes. Accordingly, the practical activity for conserving an evergreen grove of campus, the authors tried in the two lectures on school gardens and biocultural diversity. The students picked up a lot of solid garbage dumped by the other people, made a trail and transplanted many wild plants at the grove. As a consequence of those activities, they understood the importance of conservation practice and skill by themselves. It is clear that the cooperative activities enhance their environmental awareness on the biodiversity (Kimata and Saito 2013).

3) A course of lectures on the environment through many-sided approach applied "ELF Environment Learning Process" ELF: W

A course of lectures on the environment through many-sided approach for undergraduate students and another course for graduate students from Thailand were conducted and applied "ELF Environment

Learning Framework (Process).” The Process has been proposed as a framework integrated ten programs for learning the environment. The questions on a few words, “nature, environment, environmental issues and hopes of topics” through a free association and the records of their impression on the course were asked of the students taking the courses before and after the classes. The answers including many words and text were processed by SPSS Text Analytics for Surveys.

The undergraduate students recognized a word “nature” as to be such vast nature as forest, ocean, river and mountain, but these were not the familiar nature in their side. They recognized the two words “environment and environmental issues” as to be the same phenomena as global issues including acid rain, desertification, global warming and deforestation. Those issues are negative images for them. On the contrary the graduate students from Thailand recognized the words “nature and environment” as to be familiar and positive images, and only did the word “environmental issue” as to be negative. Because they changed their recognition, thought widely the environment, and added positive images after their attendances, the courses applied “ELF Environment Learning Process” were effective in understanding “environment” as a whole (Kimata et al. 2013).

4) Environment Learning Process and Need of “Environment Studies” ELF: W

It is the fundamental principle of “environment learning” that develops one’s aptitude and individual nature around an environment for living. The modernized human being needs continuing to learn the environment throughout one’s lifetime, because the whole environment as a complex system has been complicated more and more in the present age. They must train to make up their mind structure that is integrated both general knowledge scientifically in modern schools and firsthand experience traditionally in local community. It is the environment learning process that contains the flow of thinking from plain feeling to integrated intuition via analysis and synthesis.

The present situation on environmental education was analyzed in the database of many reports including GLOBE Program and the Journal “Environmental Education” and the summaries of research seminar and symposium on “environment studies.” The summaries including many words and text were processed by SPSS Text Analytics for Surveys. The environmental education has given too much weight to “Science” and is a lack of perspective in elementary and secondary schools in view of the results. Those reporters have shown various opinions, while many of them have agreed a subject “environment studies.” Therefore, the author proposes that “environment studies” integrated as a new subject will be given a position in the school education. The subject will have an original part which integrates the knowledge of all other subjects, comprehensive learning, fieldwork and outdoor activity.

5) The association for the popularization of millets and indigenous varieties ELF: M, C

Millet Straß Promotion as FAO Globally Important Agricultural Heritage Systems. The Millet Straß is a network rout of villages where farmers cultivate many traditional millet species in Kanto Mountains. These are sorghum, finger millet from Africa, foxtail millet, common millet from Central Asia and Job’s tear from South East Asia and Japanese barnyard millet. These millets are endangered species in spite of very long cultivation history in Japan, but we think these will be very important

as high-quality foods for future too. Millets are nutritious grains which are able to grow under the harsh environment. FAO had held the International Year of Millets in 2023 in order to re-evaluation those orphan crops. Common millet is continued to grow in many places throughout the Eurasia. Foxtail millet is a sacred cereal in India, Formosa, Okinawa, and main lands of Japan even today (Kimata 2023).

Epilog Monoculture of mind and the self-domestication in Anthropocene, Quaternary

Shiva (1993) had concluded as follows. Closely linked to the issue of diversity and uniformity is the issue of productivity. Higher yields and higher production have been the main push for the introduction of uniformity and the logic of the assembly line. The imperative of growth generates the imperative for monocultures. Sustainability, diversity and decentered self-organization are therefore linked, as are unsustainability, uniformity and centralization.

The concept of 'monoculture of mind' (Shiva 1993) was a pioneering idea on 'self-domestication' (Wrangham 2019). Moreover, Stout (2005) have discussed in detail on the seventh sense.

Stout (2005) had described the seventh sense as follows. What is this invisible, inescapable, frustratingly incorruptible part of us we call "conscience." The intriguing truth of the matter is that much of what we do that looks like conscience is motivated by some other thing altogether – fear, social pressure, pride, even simple habit. Conscience is something that we feel. In other words, conscience is neither behavioral nor cognitive. Conscience exists primarily in the realm of affect, better known as emotion. Conscience does not exist without an emotional bond to someone or something, and in this way, the conscience is closely allied with the spectrum of emotions we call love. If the first five senses are the physical ones – sight, hearing, touch, smell taste – and the six sense is how we refer to our institution, then conscience can be numbered seventh at best. It developed later in the evolution of our species and is still far from universal. The anonymity of evil and its maddening refusal to attach itself reliably to any particular social role, racial group, or physical type has always plagued theologians and, more recently, scientists. Throughout human history, we have tried mightily to pin down good and evil, and to find some way to account for those in our midst who would seem to be inhabited by the latter. In small and large ways, genuine conscience changes the world. Rooted in emotional connectedness, it teaches peace and opposes hatred and saves children. The problem is that not everybody has it. In fact, 4 percent of all people do not have it in USA.

I summarized the characteristics of good supporting or evil inhibiting the seventh sense (Table 64, Figure 112). I have the good or the evil experiences in my life. If the seventh sense developed later in the evolution of our species and is still far from universal, the conscience was still immature under development (Stout 2005). It involves good and evil getting. On the other hand, from another point of view, the seventh sense has instead of under development, but it is regressed evolutionally by the self-domestication in Anthropocene. If someone is self-centered and self-preservation, it means they are generally quite selfish and only do things that benefits them.

Table 64. Good vs evil getting involved in the seventh sense

Good	vs	Evil
consideration		jealousy
sincere and earnest		envy
fairness		self-preservation, personaal gain, and selfish desires
know your suffciency		dissatisfaction
truth, goodness, and beauty		honor, power, money
discussion, empathy, compromise		restrictions on freedom of speech
nonviolent, disobedience		violence, suppression
liberty, equality, fraternity		rule of law, discrimination
faith		religion
peace		war
individual, family		group （*mure*, *mura*, *shima*）, local community, city state

I thought about the formation of diverse character by making an analogy to tree (Figure 112). We make progress numerous individualities under a certain era such as the time of early Anthropocene. A human grow like to a big tree or a dwarf tree, while being influenced by the social situation.

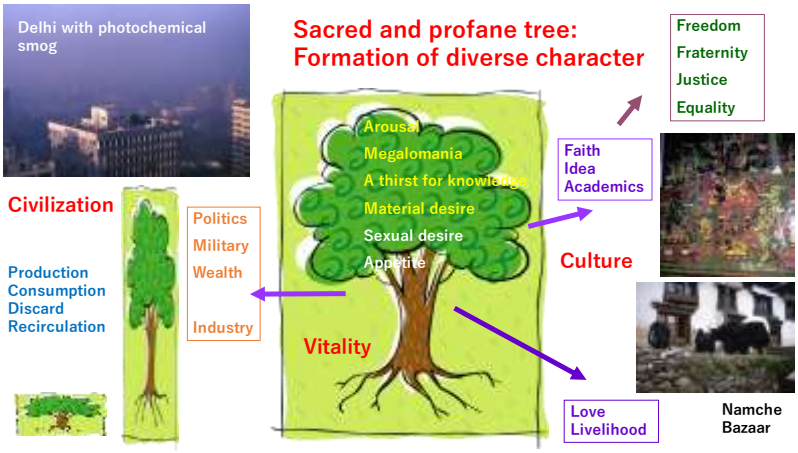


Figure 112. Formation of diverse character by making an analogy to tree

The ancients said, “Learn from past 温故知新,” “Continuity and change 不易流行,” and “I learn only to be contended 我唯足知.” Moreover, Kakabhushundi (Crow hermit) had explained the fourth period in Ramayana as follows. The remarkable characteristics of Kalyug Era are is the feeling unable to relax at all, when everybody wrapped in hostility, harmful thoughts and resentment from all directions, and tormented by fear and pain. All living things can cross the sea of bitterness, if they praise only the accomplishment story of Main God, Lord Hri (Vishnu) in this era. The brahmacariyam, prayer and spiritual awakening have disappeared in the degenerate age. However, if we have pure faith, the present days are rich in blessings. It means that we can attain moksha (be liberated) without Karmic suffering, if we will live with clear conscience.

We would like to learn the happy future of traditional lifestyle in India. We need to accept a

certain degree of Artificial Intelligence (AI), but at the same time we need to train Natural Intelligences (Nin). We take good care of the social common capital, and the right of nature (Nash 1987). We should learn from Chipko movement at the North mountains in India.

Today in the Anthropocene, we are living under severe natural and artificial condition. These are the dramatic climate change, many natural disasters, infectious diseases by the vast populations of human being and livestock, and moreover Information technology AI, many states of war and conflicts, etc. Those situations are sure to go serious hunger around the world. However, we want to find hope for children, young people and all human beings in the future.

Literature cited

Achaya, K.T. 1984. Everyyday Indian Processed Foods, National Book Trust, India, New Delhi.

Ambasta, S.P. 1986. The Useful Plants of India. Publications & Information Directorate, Council of Scientific & Industrial Research, New Delhi.

Antonovics, J. 1968. Evolution in closely adjacent plant populations. V. Evolution of self-fertility. Heredity 23: 219-238.

Applied Biosystems. 2005. AFLP Plant Mapping Protocol. Foster City, CA, USA.

Austin, D.F. 2006. Fox-tail millets (*Setaria*: Poaceae) – Abandoned food in two hemisphers. Economic Botany 60(2): 143-158.

Awantika, J., H.S. Mishara, R. Mridul and J.M. Lal. 2015. Laja (Parched Paddy): A Neutraceutical in Debility, Indian Jpurnal of Ancient Medicine and Yoga vol. 8 (2): 103-111.

Aziz, K. 1983. Indian Cooking, Publishing Group, New York.

Baker, H. G. 1955. Self-compatibility and establishment after "long-distance" dispersal. Evolution 9:347-348.

Baker, H. G. 1959. Reproductive methods as factors in speciation in flowering plants. Cold Spring Harbor Symp. Quant. Biol. 24:177-190.

Baker, H. G. 1974. The evolution of weeds. Ann. rev. Ecol. Syst. 5: 1-24.

Bellwood, P. 2005. First Farmers – The Origins of Agricultural Societies, Blackwell Publishing, UK.

Bellwood, P. and C. Renfrew ed. 2002. Examining the farming/language dispersal hypothesis, McDonald Institute for Archaeological Research, Cambridge, UK.

Berno, T. 2020. 9 Linking food biodiversity and food traditions to food tourism in small island developing states (SIDA)

Carpine, J. P. 1246. The Mongol Mission. Translated by C. Dawson (1955) to English and then by Mori, M (1964) to Japanese, Kofusha, Tokyo.

Chapman, 1996. The Biology of Grasses, CAB International, Oxon, UK.

Cho, Y. G., M. W. Blair, O. Panaud, and S. R. McCouch. 1996. Cloning and mapping of variety-specific rice genomic DNA sequences; amplified fragment length polymorphisms (AFLP) from silver stained polyacrylamide gels. Genome 39:373-378.

Chun, C., P. Jiangli, Z. Qunying and C. Shu'e. 2004. Holocene pedogenic change and the emergence and decline of rain-fed cereal agriculture on Chinese Loess Plateau. Quaternary Science Reviews 23:2525-2535.

Church, A. H. 1886. Food-grains of India. The Committee of Council on Education, London.

Chandra, U. and M. N. Koppar. 1990. Diversity and domestication of minor millet species in Indian sub-continent. Indian Journal of Plant Genetic Resources 3(2):47-58.

Chang, T.T. 1995. 32 Rice, Smartt, J. and N.W. Simmonds (ed.), Evolution of Crop Plants, Longman Scientific & Technical, UK.

Clayton, W.D. and S.A. Renvoize 1986. Genera Graminum; Grasses of the World, Her Majesty's Stationery Office, London, U.K.

Conklin, H.C. 1980. A Study of Environment, Culture, and Society in Northern Luzon. Ethnographic Atlas Ifugao Redux, Charles Augustus Marcum III, The American Geographical Society of New York.

de Wet, J. M. J., K. E. Prasada Rao, M. H. Mengesha, and D. E. Brink. 1983a. Diversity in kodo millet, *Paspalum scrobiculatum*. Economic Botany 37:159-163.

de Wet, J. M. J., K. E. Prasada Rao, M. H. Mengesha, and D. E. Brink. 1983b. Domestication of sawa millet (*Echinochloa colona*). Economic Botany 37:283-291.

de Wet, J. M. J., K. E. Prasada Rao, M. H. Mengesha, and D. E. Brink. 1983c. Systematics and domestication of *Panicum sumatrense* (Gramineae), Journal d'Agriculture Traditional et Botanique Applique 30:159-168.

de Candole, A. 1886. Origin of Cultivated Plants. Kegan Paul, Trench & Co., London, p376-378.

d'Ennequin, M. L. T., O. Panaud, B. Toupance and A. Sarr. 2000. Assessment of genetic relationships between *Setaria italica* and its wild relative *S. viridis* using AFLP markers. Theor Appl Genet 100: 1061-1066.

Ehrendorfer, F. 1965. Dispersal mechanisms, genetic systems, and colonizing abilities in some flowering plant families. In H. G. Baker and G. L. Stebbins, ed., The Genetics of Colonizing species p. 331-351. Academic Press, New York.

Fuller, D. Q., and M. Madella. 2000. Issues in Harappan archaeobotany: Retrospect and prospect. in Indian Archaeology in Retrospect, Vol. II. Protohistory. In: S. Settar and Ravi Korisettar (eds) Publications of the Indian Council for Historical Research, Manohar, New Delhi, pp317-390.

Fuller, D. Q., R. Korisettar, and P. C. Venkatasubbaiah. 2001. Southern Neolithic cultivation systems: A reconstruction based on archaeobotanical evidence. South Asian Studies 17: 171-187.

Fuller, D.Q. and M. Madella. 2001. Issues in Harappan Archaeology: Retrospect and Prospect. In: Settar S. Krisettar R. (eds.) Protohistory – Archaeology of the Harappan Civilization. Manohar, New Delhi, pp317-390.

Fuller, D. 2001. Fifty years of archaeobotanical studies in India: laying a solid foundation, Indian Archaeology in Retrospect, vol. III.: Archaeology and Interactive Disciplines, eds. S. Setter & R. Korisettar. New Delhi: Manohar: 247-363.

Fuller, D. 2002. B. Asia and Oceania. Chapter 16 An Agricultural Perspective on Dravidian Historical Linguistics: Archaeological Crop Packages, Livestock and Dravidian Crop Vocabulary.

Fuller, D. 2002. An agricultural perspective on Dravidian historical linguistics: Archaeological crop packages, livestock and Dravidian crop vocabulary. Pp.191-213. in P. Bellwood and C. Renfrew eds., Examining the Farming/Language Dispersal Hypothesis, McDonald Institute for Archaeology Research, Cambridge.

Fukuda, I. and M. Kimata. 1983. III-3. Legumes in Nepal. In ed. by I. Fukuda, Scientific Research on the Cultivation and Utilization of Major Crops in Nepal. pp.40-58. The Japanese Expedition of Nepalese Agricultural Research.

Fukunaga, K., Z. Wang, K. Kato, and M. Kawase. 2002. Geographical variation of nuclear genome RFLPs and genetic differentiation in foxtail millet, *Setaria italica* (L.) P. Beauv. Genetic Resources and Crop Evolution 49: 95-101.

Fussell. B. 1992, The story of corn, University of New Mexico Press.

Gerard, G. 1597. The Herball or Generall Historie of Plantes. Norton, London, pp73-81.

Goodman, M.M. 1995, *Zea mays* (Gramineae – Maydeeae), ed. by J. Smartt and N. W. Simmonds, Evolution of Crop Plants, Longman Scientific & Technical, Essex UK.

Gorman, C. 1977. A Priori Models and Thai Prehistory: A Reconsideration of the Beginnings of

Agriculture in Southeastern Asia, Reed, C.A. (ed), Origins of Agriculture, Mouton Publishers.
Graeber, D. and D. Wengrow, 2021. Thhe Dawn of Everything – A New History of Humanity, Picador, NY, USA.
Harper, J. L. 1967. A Darwinian approach to plant ecology. J. Ecol. 55:247-270.
Harper, J. L. and J. Ogden. 1970. The reproductive strategy of higher plants. I. The concept of strategy with special reference to *Senecio vulgaris* L. J. Ecol. 58: 681-698.
Harlan, J. 1995. *Triticale*, *Sorghum halepense*, *Zea*, *Hordeum*, *Secale*, ed. by J. Smartt, and N. W. Simmonds, Evolution of Crop Plants, second edition, Longman Scientific & Technical, UK.
Howard, H.W. 1947. Chromosome numbers of British species of the genus *Rorippa* Scop. (part of the genus *Nasturtium* R.Br.). Nature 159: 66.
Iltis, H.H. 1983. From Teosinte to Maize: The Catastrophic Sexual Transmutatio, Science 222, no.4626.
Iltis, H.H. 1987. Maize Evolution and Agricultural Origin, Grass Systematics and Evolution. Eds. E. R. Soderstrom et al. Washington, D.C. Smithonian Institution Press.
Jain, S. K. 1976. The evolution of inbreeding in plants. Ann. Rev. Ecol. Syst. ': 469-495.
Jonsell, B. 1968. Studies in the North-West European species of *Rorippa* s. str. Symb. Bot. Upsaliens 19 (2): 1-211.
Jonsell, B. 1973. Taxonomy and distribution of *Rorippa* (Cruciferae) in the Southern U.S.S.R. Svensk Botanisk Tidskrift, Bd 67: 281-302.
Jain, S. K. 1976. The evolution of inbreeding in plants. Ann. Rev. Ecol. Syst. ': 469-495.
Jonsell, B. 1968. Studies in the North-West European species of *Rorippa* s. str. Symb. Bot. Upsaliens 19 (2): 1-211.
Jonsell, B. 1973. Taxonomy and distribution of *Rorippa* (Cruciferae) in the Southern U.S.S.R. Svensk Botanisk Tidskrift, Bd 67: 281-302.
Harlan, J.R. 1977, The Origins of Cereal Agriculture in the Old World, Reed, C. A. (ed), Origins of Agriculture, Mouton Publishers, Paris.
Harlan, J. R. 1992. Crops and Man. Amer. Soc. Agro. And crop Sci. Soc. Amer., Madison, Wisconsin.
Harari, Y.N., 2014, Sapiens – A Brief History of Humankind,
Harari, Y.N., 2017, Homo Deus - A Brief History of Tomorrow, Daniel Kahhneman,
Harries, H.C. 1995, 76 Coconut, Smartt, J. and N.W. Simmonds (ed.), Evolution of Crop Plants, Longman Scientific & Technical, UK.
Hunt, H.V. and M. K. Jonse. 2006. Pathway across Asia: exploring the history of *Pnicum* and *Setaria* in the Indian subcontinent. International Seminar on the “First Farmers in Global Perspective.” Lacknow, p.53-68.
Hunter, D., E. Monville-Ora, B. Burgos, C. N. Rogel, B. Calub, J. Gonsalves and N. Lauridsen (ed.), 2020. Agrobiodiversity, School Gardens and Healthy Diets – Promoting Biodiversity, Food and Sustainable Nutrition, Bioversity International, Routledge, NY, USA.
Hunter, D., T. Borelli and E. Gee (ed). 2020. Biodiversity, Food and Nutrition – A New Agenda for Sustainable Food Systems, Routledge, London.
Huang, Kurata et al. 2012. A map of rice genome variation reveals the origin of cultivated rice, Nature 490:497-501.
Ishikawa, Y. 2007. Domestication of kodo millet (*Paspalum scrobiculatum* L.) in India. Doctoral

thesis for Kyoto University.
Iwata, K. 1986, Human, Play and Nature – Buck ground of South East Asia (in Japanese), Nihon Hoso Shuppan Kyoukai, Tokyo.
Jonse, M. 2004. Between Fertile Crescents: Minor Grain Crops and Agriculture Origins. Ed. M. Jonse. “Traces of ancestry: studies in hounour of Colin Renfrew.” University of Cambridge, Cambridge, p127-135.
Katayama, T. 片山忠夫　1987、熱帯アジアの野生稲の分布とその特性、東南アジア研究 25 巻 1 号：3-27。
Kawase, M. and S. Sakamoto. 1982. Geographical distribution and genetic analysis of phenol color reaction in foxtail millet, *Setaria italica* (L.) P. Beauv. Theor. Appl. Genet. 63: 117-119.
Kawase, M. 1987. Variation and distribution of millets in South India. Pages 5-14 *in* S. Sakamoto, ed., A preliminary report of studies on millet cultivation and its agro-postal culture complex in Indian sub-continent, I (1985). Kyoto University, Kyoto, Japan.
Kawase, M. 1991.　Millet and their phylogeny in Indian Subcontinent.　pp.33-98. in Sakamoto, S. ed., Agro-pastoral Culture Complex of Millets in Indian Subcontinent, Gakkai-Shuppan Center, Tokyo (in Japanese).
Kimata, M. 1978. Comparative studies on the reproductive systems of *Mazus japonicus* and *M. miquelii* (Scrophulariaceae).　Pl. Syst. Evol. 129: 243-253.
Kimata, M. and S. Sakamoto.　1979. Comparative studies on the population dynamics of *Mazus japanicus* and M. Miquelii, Scrophulariaceae, Bot. Mag. Tokyo 92: 123-134.
Kimata, M. and T. Nakagome. 1982. Comparative studies on the growth habit and growth pattern of *Coix lacryma-jobi* var. *ma-yuen* and var. *lacryma-jobi*, Gramineae. Bull. Tokyo Gakugei Uniiversity, Sect. VI. 34:1-10.
Kimata, M. 1983. Comparative studies on the reproductive systems of *Cardamine flexuosa*, *C. impatiens*, *C. scutata* and *C. lyrata*, Cruciferae.　Bot. Mag. Tokyo 96: 299-312.
Kimata, M. 1983. Characteristics of some grain crops, garden crops and weeds, and methods of cooking grain crops in Nepal.　In ed. by I. Fukuda, Scientific Research on the Cultivation and Utilization of Major Crops in Nepal. pp.40-58. The Japanese Expedition of Nepalese Agricultural Research, Tokyo.
Kimata, M., Y. Kimura, N. Kawaguchi, and H. Shibata. 1986. Cultivation and utilization of millet in Sarugawa region, Hokkaido. Kikan-Jinruigaku 17(1): 22-53 (in Japanese).
Kimata, M. 1987. Grain crop cookery in South India, Research Team for the Studies on Millet Cultivation and its Agro-pastoral Culture Complex in the Indian Subcontinent, Kyoto University, pp.41-55.
Kimata, M. 1989. Grain crop cookery on the Deccan Plateau, Research Team for the Studies on Millet Cultivation and its Agro-pastoral Culture Complex in the Indian Subcontinent, Kyoto University, pp.33-50.
Kimata, M. 1991.　Food culture of millet in Indian Subcontinent. pp. 173-222. in Sakamoto, S. ed., Agro-pastoral Culture Complex of Millets in Indian Subcontinent, Gakkai-Shuppan Center, Tokyo (in Japanese).
Kimata, M. and S. Sakamoto. 1992. Utilization of several species of millet in Eurasia. Bull. Field Studies Inst., Tokyo Gakugei University, 3:1-12.

Kimata, M. 1994. Geographical variation and ethnobotany of *Panicum miliaceum.* Shuseibutsugakukennkyu 18: 5-12 (in Japanese).

Kimata, M. and H. Kobayashi 1996, The interspecific differentiation of *Cardamine flexuosa*, Cruciferae, in Japan and Nepal, Environmental Education Research, Tokyo Gakugei University. 6:9-21.

Kimata, M. 1997. Cultivation and utilization of millets and other grain crops in West Turkestan. In: Kimata M.(ed). A Preliminary Report of the Studies on Millet Cultivation and Environmental Culture Complex in West Turkestan. Tokyo Gakugei University, pp1-17.

Kimata，M. and A. Seetharam. 1997. Processing and utilization of small millets in Eurasia. pp.112-114. National Seminar on Small Millets, Indian Council of Agricultural Research and Tamil Nadu Agricultural University.

Kimata, M., S.G. Mantur and A. Seetharam. 1997. Cultivation and utilization of small millets in hill regions, Uttar Pradesh and Himachal Pradesh, India. Environmental Education Research, Tokyo Gakugei University. 7:33-43.

Kimata，M. and A. Seetharam. 1997. Processing and utilization of small millets in Eurasia. pp.112-114. National Seminar on Small Millets, Indian Council of Agricultural Research and Tamil Nadu Agricultural University.

Kimata, M., M. Kanoda and A. Seetharam. 1998. Traditional and modern utilizations of millets in Japan. Environmental Education Studies, Tokyo Gakugei University 8:21-29.

Kimata, M., S. Fuke and A. Seetharam. 1999. The physical and nutritional effects of the parboiling process on the grains in small millets. Environmental Education Studies, Tokyo Gakugei University 9:25-40.

Kimata, M., E.G. Ashok and A. Seetharam. 2000. Domestication, cultivation and utilization of two small millets, *Brachiaria ramosa* and *Setaria glauca* (Poaceae), in South India. Economic Botany 54(2):217-227.

Kimata, M. and M. Negishi. 2002. Geographical distribution of proso millet, *Panicum miliaceum* L. on iodostarch and phenol reactions; with special references to a northern propagation route into Japanese Islands. Environmental Education Studies, Tokyo Gakugei University. 12:15-22.

Kimata, M. and Y. Ishikawa. 2004. Mimicry and mixed cropping of *Setaria glauca* with *Panicum sumatrense* or *Paspalum scrobiculatum*, Ninth International Congress of Ethnobiology. A58.

Kimata, M, T. Kawamura, T. Maeno and S. Endo. 2007. Fatty acid composition of neutral lipids in seed grains of *Panicum miliaceum* L. Ethnobotanical Notes 2: 8-13.

Kimata, M., M. Nonomura and Y. Osawa 2007, Formation of Vernacular Names for Weeds and Plant Naming Programmes for Re-creation of Children's Culture, Environmental Education 17（1）: 13-32.

Kimata, M. 2009. Domestication of *Panicum miliaceum* L. ed. N. Yamamoto "Ethnobiological Studies on the Domestication of Plants and Animals," Senri Ethnological Reports 84: 205-223 (in Japanese).

Kimata, M. and T. Saito 2013, Environmental Awareness and its Transformation in Reaction to Biodiversity Conservation and Maintenance on a University Campus, Environmental Education 22（3）: 2-13.

Kimata, M. 2023, Never ending story on millets, Millet Newsletter 38 : 35-37.

Kobayashi, H. 1987. Mimic and associated weeds with millets and cultivation methods of millets in the Indian subcontinent. In: Sakamoto S (ed) A preliminary report of studies on millet cultivation and its agro-postal culture complex in Indian sub-continent, I (1985). Kyoto University, Kyoto, Japan, pp 15-40.

Kobayashi, H. 1989. Mimic and associated weeds with millet and rice cultivation in Orissa and Maharashtra in India. In: Sakamoto S (ed) A preliminary report of studies on millet cultivation and its agro-postal culture complex in Indian sub-continent, II (1987). Kyoto University, Kyoto, Japan, pp 11-32.

Kobayashi, H. 1991. The origin of secondary crops of millet in India. pp. 99-140 in Sakamoto, S. ed., Agro-pastoral Culture Complex of Millets in Indian Subcontinent, Gakkai-Shuppan Center, Tokyo (in Japanese).

Kobayashi, H. and M. Kimata. 1989. Millets in Maharashtra and Orissa in India. Research Team for the Studies on Millet Cultivation and its Agro-pastoral Culture Complex in the Indian Subcontinent, Kyoto University, pp.1-9.

Lakshmi, M., M. Parani, S. Rajalakshmi and A. Parida. 2002. Analysis of species relationship among seven small millets using molecular markers, J. Plant Biochemistry & Biotechnology 11: 85-91.

Lefebvre, C. 1970. Self-fertility in maritime and zinc mine populations of *Armeris maritima* (Mill.) Willd. Evolution 24: 571-577.

Lin, H., G. Liao, C. Chang, C. Kuoh and S. Chang. 2012. Genetic diversity in the foxtail millet (*Setaria italica*) germplasm as determined by agronomic traits and microsatellite markers. Australian Journal of Crop Science 6(2): 342-349.

Лысов, В. Н. 1968. Просо. Колос, Ленинраа.

Lyssov, V. N. 1975. Proso (*Panicum* L.). In: A.S. Krotov (ed.). Flora of cultivated plants. Vol. III. Groat Crops (buckwheat, millet, rice). P.119-236. Kolos, Leningrad.

Maeshwari , J. K. 1987. Interdisciplinary approaches in ethnobotany. ed. by Jain, S. K. In A Manual of Ethnobotany. Scientific Publishers, Jodhpur, India.

Meadow, R.H. 1986. The Geographical and paleoenvironmental Setting of Tepe Yahya. eds. C. C. Lamberg-Karlovsky and T. W. Beale. “Excavation at Tepe Yahya, Iran 1967-1975, The Early Periods,” American School of Prehistoric Research Bulletin 38: 21-38. Harvard University Press, Massachusetts.

Meadow, R.H. 1986. The Geographical and paleoenvironmental Setting of Tepe Yahya. eds. C. C. Lamberg-Karlovsky and T. W. Beale. “Excavation at Tepe Yahya, Iran 1967-1975, The Early Periods,” American School of Prehistoric Research Bulletin 38: 21-38. Harvard University Press, Massachusetts.

Mithen, S. 1996. The Prehistory of the Mind – The cognitive origins of art, religion and science, Thames and Hadson Ltd., London, UK.

Miwa, S. 三輪茂雄 1989、ものと人間の文化史 61、篩、法政大学出版局、東京。

Murray, M. G. and W. F. Thompson. 1980. Rapid isolation of high molecular weight plant DNA. Nucleic Acids Research 8: 4321-4325.

Mullingan, G.A. and A.E. Porsild. 1968. A natural first-generation hybrid between *Rorippa barbareaefolia* and *R. islandica*. Canadian Journal of Botany 46: 1079-1081.

Murdock, G.P., 1959. Africa – Its Peoples and Their Culture History, McGraw-Hill Book Company,

NY, USA.
Nabham, G. and J. M. J. de Wet. 1984. *Panicum sonorum* in Sonoran Desert Agriculture. Economic Botany 38: 65-82.
Nakatani, H. and M. Kimata. 1993. Comparative study of the reproductive systems of two naturalized strains, *Rorippa sylvestris* (L.) Besser in Hokkaido and Nagano Prefecture. Bull.Field Studies Inst. Tokyo Gakugei Univ., 4: 33-38.
Nakao, S. 1967. The origin of Agriculture. pp.329-496 in M.Morishita and T. Kira, eds., The Nature --- ecological studies, Chuoukouronsha, Tokyo (in Japanese).
Nakao, S. 1972. The Origin of Cooking, Nihon Hoso Shuppan Kyoukai, Tokyo (in Japanese).
Nash, R.F. 1987. The Rights of Nature – A history of Environmental Ethics, University of Wisconsin Press, USA.
Nasu, H. 那須浩郎 2018、縄文時代の植物のドメスティケーション、第四紀研究 57(4):109-126。
Nei, M., and S. Kumar. 2000. Molecular Evolution and Phylogenetics. Oxford University Press, New York.
Nesbitt, M. 2005. Grain. In: Prance G. (ed). The Cultural History of Plants. Routledge, New York, pp. 45-60.
Nesbitt, M., and G. D. Summers. 1988. Some recent discoveries of millet (*Panicum miliaceum* L.) and *Setaria italica* (L.) P. Beauv.) at excavations in Turkey and Iran. Anatolian Studies 38: 85-97.
Oka, H. I. and H. Morishima 1967. Variations in the breeding systems of wild rice *Oryza perennis*, Evolution 21:249-258.
Ohnishi, O. 1998. Search for the wild ancestor of buckwheat III. The wild ancestor of cultivated common buckwheat, and of Tartary buckwheat. Economic Botany 52:123-133.
Ohono, S. 2004. Yayoi Civilization and South India (in Japanese), Iwanami shoten, Tokyo.
Padulosi, S., E.D. Israel Oliver King, D. Hunter and M.S. Swaminathan, 2022. Orphan Crops for Sustainable Food and Nutrition Security – Promoting Neglected and Underutilized Species, Routledge, London.
Pokharia, A.K. 2008. Palaeoethnobotanical record of cultivated crops and associated weeds and wild taxa from Neolithic site, Tokwa, Uttar Pradesh, India. Current Science 94(2): 248-255.
Reed, C.A. (ed.) 1977. Origins of Agriculture, Mouton Publishers, Paris, France.
Roach, B.T. 1995, 34 Sugar canes, Smartt, J. and N.W. Simmonds (ed.), Evolution of Crop Plants, Longman Scientific & Technical, UK.
Sahni, J. 1986. Classic Indian Cooking, Dorling Kindersley, London.
Sakamoto, S. 1974, Intergeneric hybridization among three species of *Heteranthelium*, *Eremopyrum* and *Hordeum*, and its significance for the genetic relationships within the tribe Triticeae, New Phytologist 73: 341-350.
Sakamoto, S. 1987. Origin and dispersal of common millet and foxtail millet. Japan Agricultural Research quarterly 21(2):84-89.
Sakamoto, S. 1988. Origins and Dispersals of Millets – An Eurasian Ethnobotany. Nihonhoso-shuppan-kyokai, Tokyo, Japan (in Japanese).
Sakamoto, S. 1982. Waxy/non-waxy and their geographical distribution of endosperm starch in

cereals. Starch Science 29: 41-55 (in Japanese).
Sakamoto, S. 1988. Dispersal Route of Millets: from ethnobotanical history through Eurasia. Nihonhoso-shuppankyokai, Tokyo (in Japanese).
Sakamoto, S. 1987. Origin and dispersal of common millet and foxtail millet. Japan Agricultural Research quarterly 21(2):84-89.
Sakamoto, S. 1988. Origins and Dispersals of Millets – An Eurasian Ethnobotany. Nihonhoso-shuppan-kyokai, Tokyo, Japan (in Japanese).
Sakamoto, S. 1987. A preliminary report of studies on millet cultivation and its agro-pastoral culture complex in Indian sub-continent, I (1985). Kyoto University, Kyoto, Japan.
Sakamoto, S. 1989. A preliminary report of studies on millet cultivation and its agro-pastoral culture complex in Indian sub-continent, II (1987). Kyoto University, Kyoto, Japan.
Sakamoto, S. 1991. Agro-pastoral Culture Complex of Millets in Indian Subcontinent, Gakkai-Shuppan Center, Tokyo (in Japanese).
Sasaki, K. 1994. 佐々木高明 1994、根栽農耕文化と雑穀農耕文化の発見―中尾佐助博士の農耕文化の大類型区分をめぐって、農耕の技術と文化 17 : 104-133、農耕文化研究振興会。
Saur, C.O. 1952. Agricultural Origns and Dispersal, The American Geographical Society.
Scholz, H. and V. Mikoláš. 1991. The weedy representatives of proso millet (*Panicum miliaceum*, Poaceae) in Central Europe. Thaiszia, Kosice 1: 31-41.
Scott, J.C. 2017. Against the Grain - A Deep History of the Earliest States, Yale Ubiversity Press, New Haven and London, UK.
Scott, J.C. 2009. The Art of Not Being Governed – An Anarchist History of Upland Southeast Asia, Yale University Press, USA.
Sehgal, J. L., D. K. Mandal, C. Mandal, and S. Vadivelu. 1992. Agro-Ecological regions of India. Oxford and IBH Publishing Co., New Delhi, India.
Shinohara, T. and D. Nishiya 篠原徹・西谷大 2011、野生植物と栽培植物の境界と生業との関係性、国立歴史民俗博物館研究報告第 164 : 7-33Sauer, J. D. 1976. Grain Amaranthus (*Amaranthus* sp., Amaranthaceae). In Evolution of Crop Plants, ed. Simonds, N. W., pp.4-6. Longman, London.
Shiva, V. 1992. The Violence of the Green Revolution – Third World Agriculture, Ecology and Politics, The Other India Oress, Goa, India.
Shiva, V. 1993. Monocultures of the Mind, Third World Network, Malaysia.
Simmonds, N.W. 1995. 72 Bananas, Smartt, J. and N.W. Simmonds (ed.), Evolution of Crop Plants, Longman Scientific & Technical, UK.
Singh HB, Arora RK (1972) Raishan (*Digitaria* sp.) - a minor millet of the Kashi Hills, India. Economic Botany 26:376-380.
Southworth, F.C. 2005. Linguistic Archaeology of South Asia. Routledge Curzon, London.
Stebbins, G. L. 1950. Variation and Evolution in Plants. Columbia University Press, NY, USA.
Stebbins, G. L. 1957. Self-fertilization and population variability in the higher plants. American Naturalist 91:337-354.
Stebbins, G. L. 1958. Longevity, habitat, and release of genetic variability in the higher plants. Cold Spring Harbor Symp. Quant. Biol. 23:365-378.
Stebbins, G. L. 1974. Flowering Plants. Harvard Univ. Press. Massachusetts, U. S.

Stout, M. 2005. The Sociopath Next Door – The Ruthless Versus the Rest of Us, MJF Books, NY, USA.

Suyama, Y. 2001. AFLP analysis, In: The Society for the Study of Species Biology (ed), Molecular Ecology of Woody Species (in Japanese). Bun-ichi Sogo Shuppan Co., Tokyo, pp.251-262

Vavilov, N. I. 1926. Studies on the Origin of Cultivated Plants. Inst. Bot. Appl. Amel. Plants. Breeding 16:1-245. Leningrad.

Wang, Y., H. Zhi, W. Li, H. Li, Y. Wang, Z. Huang and X. Diao. 2009. A novel genome of C and the first autotetraploid species in the *Setaria* genus identified by genomic *in situ* hybridization. Genetic Resources and Crop Evolution 56(6): 843-850

Weber, S. A. 1992. South Asian Archaeobotanical Variability. In: Jarrige C (ed.). South Asian Archaeology 1989. Prehistory Press, Madison Wisconsin, pp 283-290

Weber, S. A. 1996. Distinguishing change in the subsistence and the material records: The interplay of environment and culture. Asian Perspectives 35(2):155-163.

Welth, E. 1954、(Yabuuchi, Y. and J. Iinuma 薮内芳彦・飯沼二郎訳 1968)『農業文化の起原―堀棒と鍬と犂』、岩波書店。

World Rainforest Movement 1991. Biodiversity, Social & Ecological Perspectives, World Rainforest Movement, Malaysia

Wrangham, R. 2009. Catching Fire - How cooking made us human, A member of the Perseus Books Group, New York, USA.

Wrangham, R. 2019. The Goodness Paradox – The Strange Relationship Between Virtue and Violence in Human Evolution.

Xuehui Huang, Nori Kurata, […] Bin Ham, 2012. A map of rice genome variation reveals the origin of cultivated rice, Nature vol. 490: 497-501.

Yabuno, T. 1962. Cytotaxonomic studies on the two cultivated species and the wild relatives in the genus *Echinochloa*. Cytologia 27:296-305.

Yamamoto, N. (ed.), 2009. Ethnobiological Studies on the Domestication of Plants and Animals, National Museum of Ethnology, Osaka, Japan.

Zhao, M., H. Zhi, A. N. Doust, W. Li, Y. Wang, H. Li, G. Jia, Y. Wang, N. Zhang and X. Diao. 2013. Novel genomes and genome constitutions identified by GISH and 5s rDNA and knotted 1 genomic sequences in the genus *Setaria*. BMC Genomics 14: 244. http://www.biomedcentral.com/1471-2164/14/244. Accessed 10 August 2013

Zohary, D. and M. Hopf. 2000. Domestication of Plants in the Old World: The origin and spread of cultivated plants in West Asia, Europe and the Nile Valley. Oxford University Press, London.

Zohary, D. and M. Hopf. 2000. Domestication of Plants in the Old World, Oxford University Press, UK.

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Essentials of Ethnobotany on Millets: Their Origin and Dispersal around Indian Subcontinent

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