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

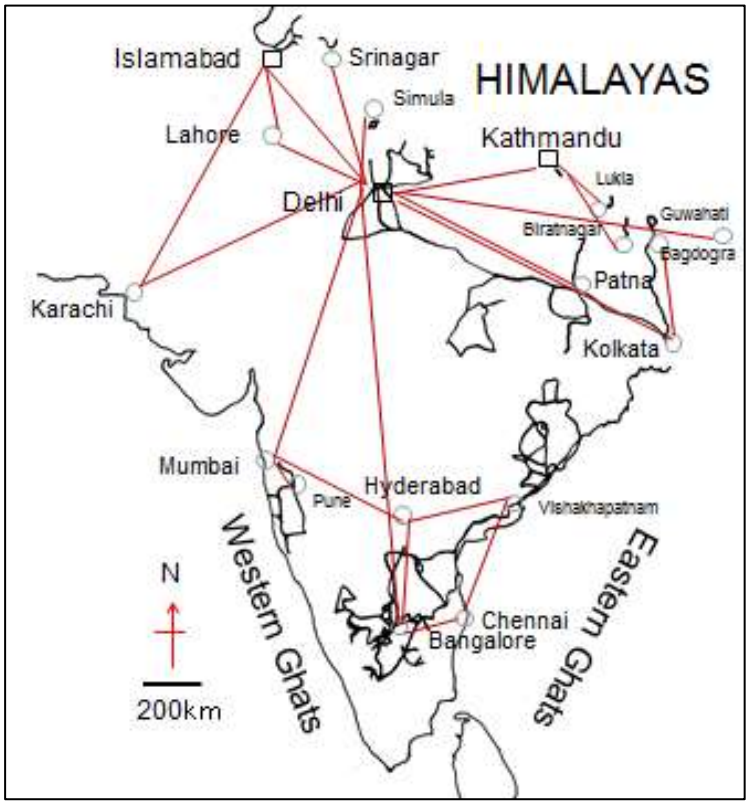

Figure 31. Expedition routes in the Himalayas, Western Ghats and Eastern Ghats.

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-wesern 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).

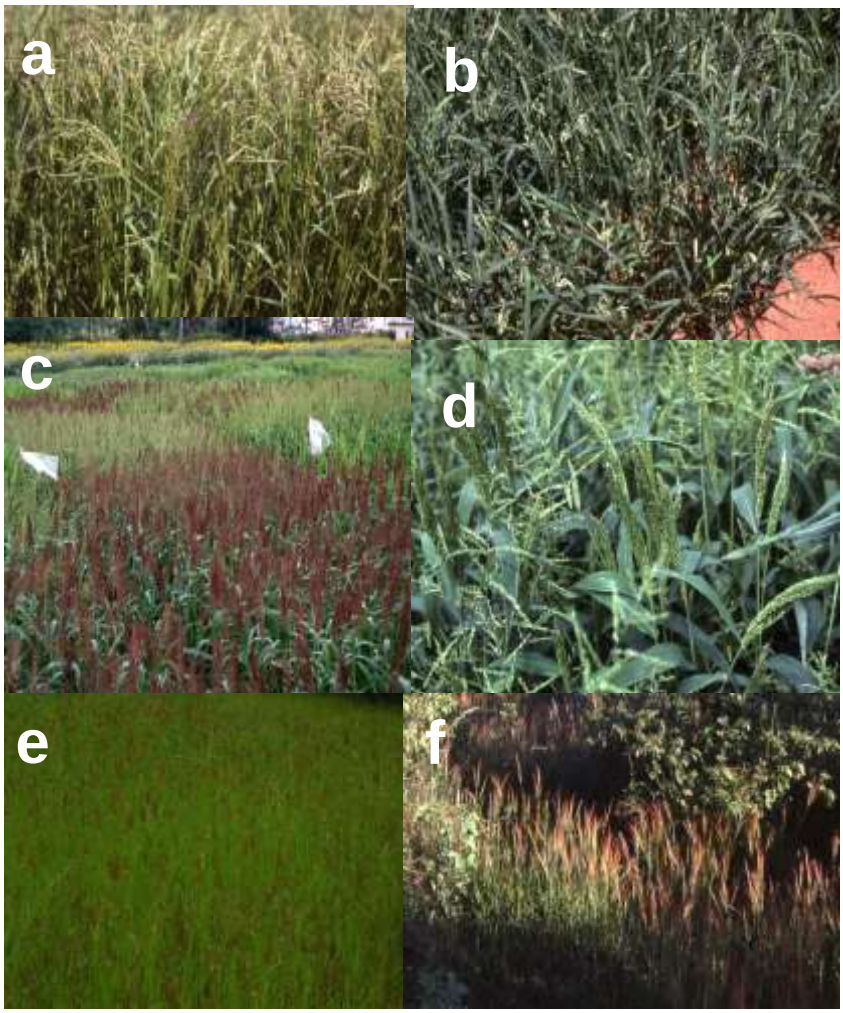

Figure 32. Five species of millet domesticated in the Indian subcontinent and wild rice:
a, *Panicum sumatrense*; b, *Paspalum scrobiculatum*; c, *Echinochloa frumentacea*; d, *Brachiaria ramosa*; e, *Setaria pumila*; and f, *Oryza rufipogon* in the irrigation canal.

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.

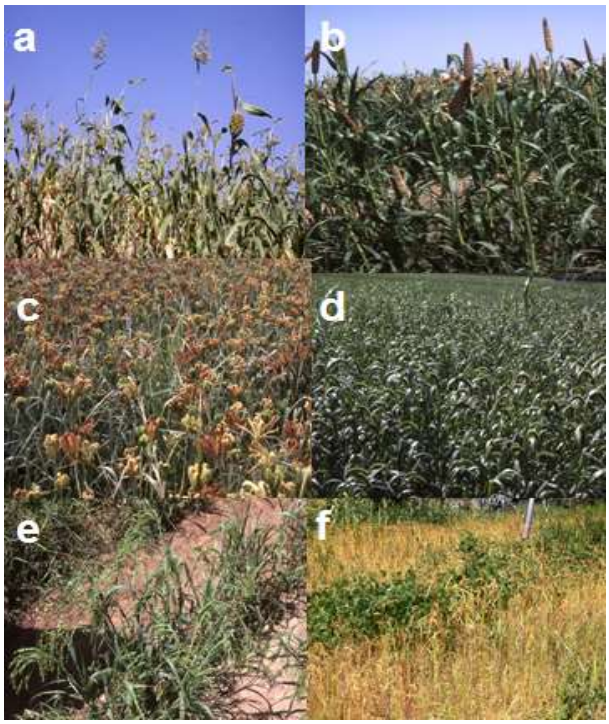

Figure 33. Five species of millet introduced into the Indian subcontinent and a field of inter-cropping with *Setaria italica* and *Grycine max*:

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).

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.

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.

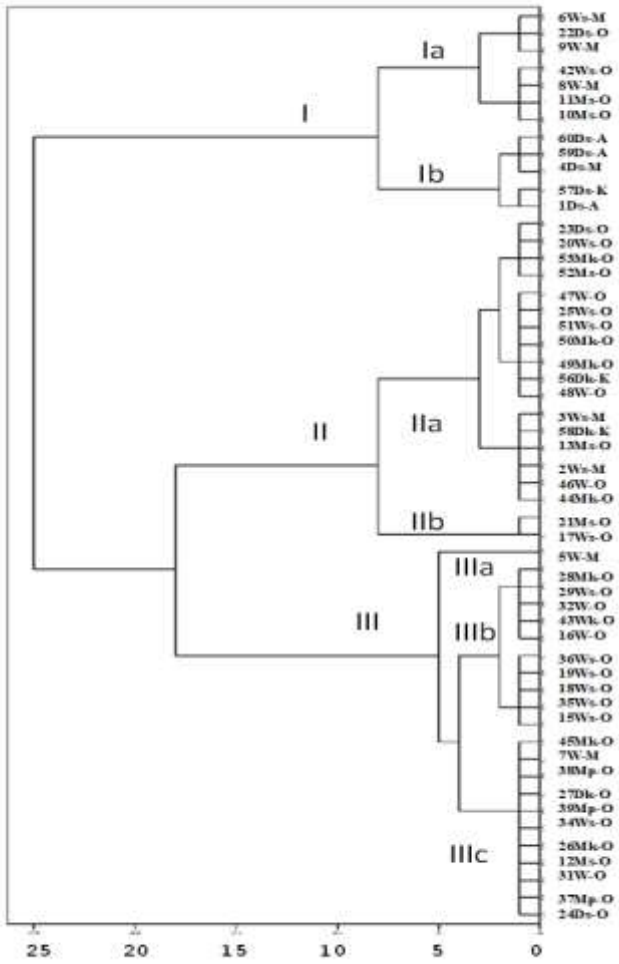

Figure 33. Cluster analysis of six morphological characteristics

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 m^2) 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.

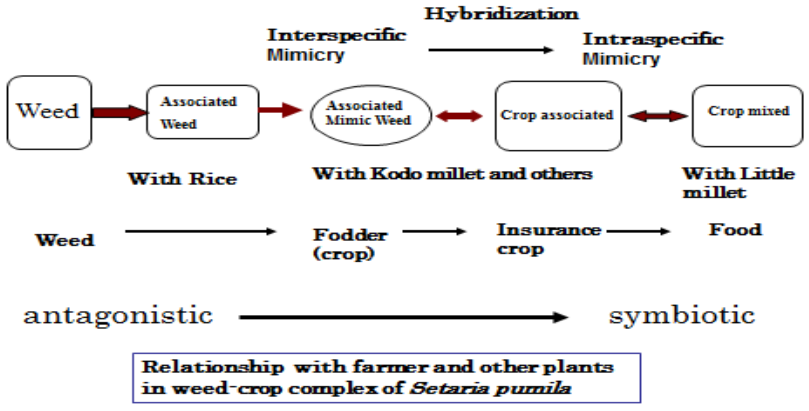

Figure 34. Domestication process of *Setaria pumila*

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).

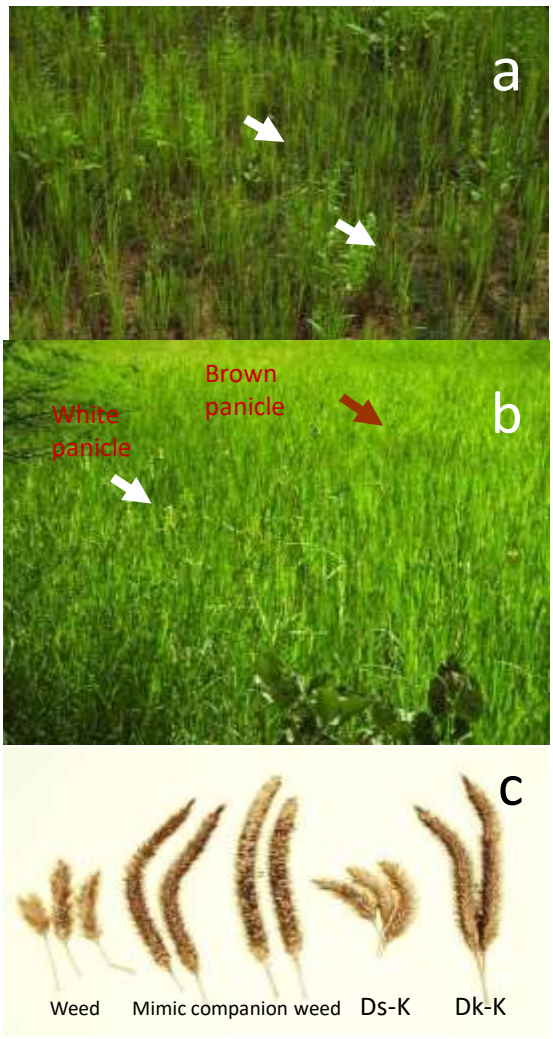

Figure 35. Fields of *Setaria pumila* mixed with *Pas. scrobiculatum* (a) and with *P. sumatrense* (b) in South India, and spikes of *S. pumila* (c):

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* (Figure 35e), flour porridge, *sankati* (Figure 35f) and semi-solid porridge, *uppitu* (Figure 35g).

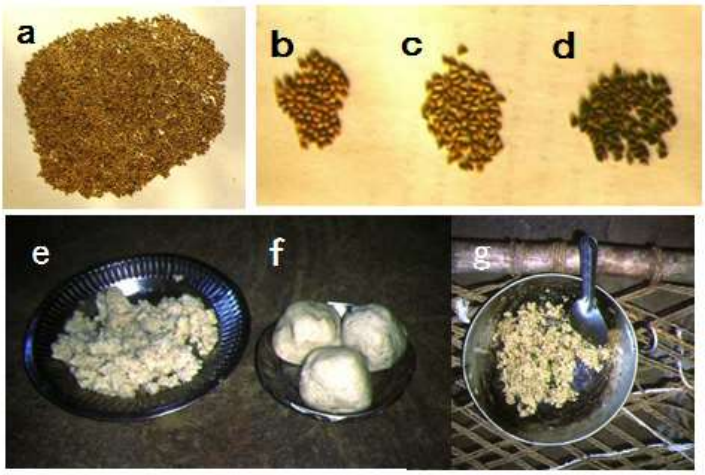

Figure 36. Seed mimicry of *S. pumila* to *P. sumatrense* and three foods made from their mixed grains at Jalaripali village, Andhra Pradesh:
a) mixed grains harvested and sold; after identified them, b) brown seeds of *P. sumatrense*, c) brown seeds and d) black seeds of *S. pumila*; e) *annamu* (boiled grain), f) *sankati* (thick flour porridge) and g) *uppitu* (semi-solid porridge).

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 m^2) 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.

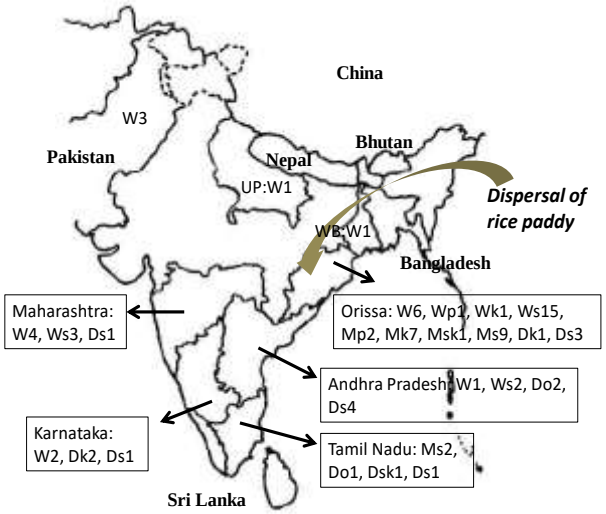

Figure 37. Sites from which *S. pumila* and the related species were collected in the Indian subcontinent.

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 $g \cdot m^{-2}$. 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.

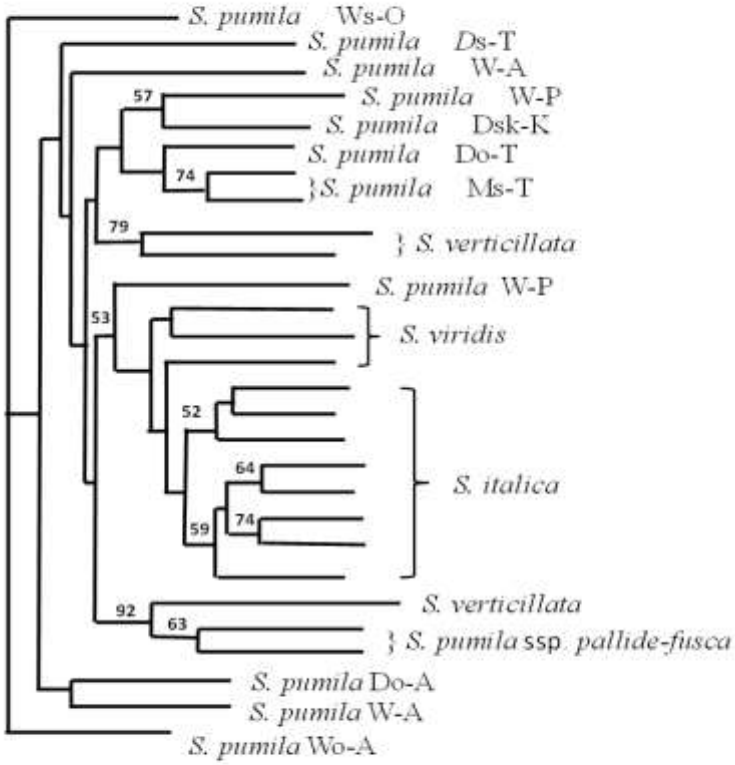

Figure 38. Dendrogram of neighbor-joining method based on AFLP markers of genus *Setaria.*

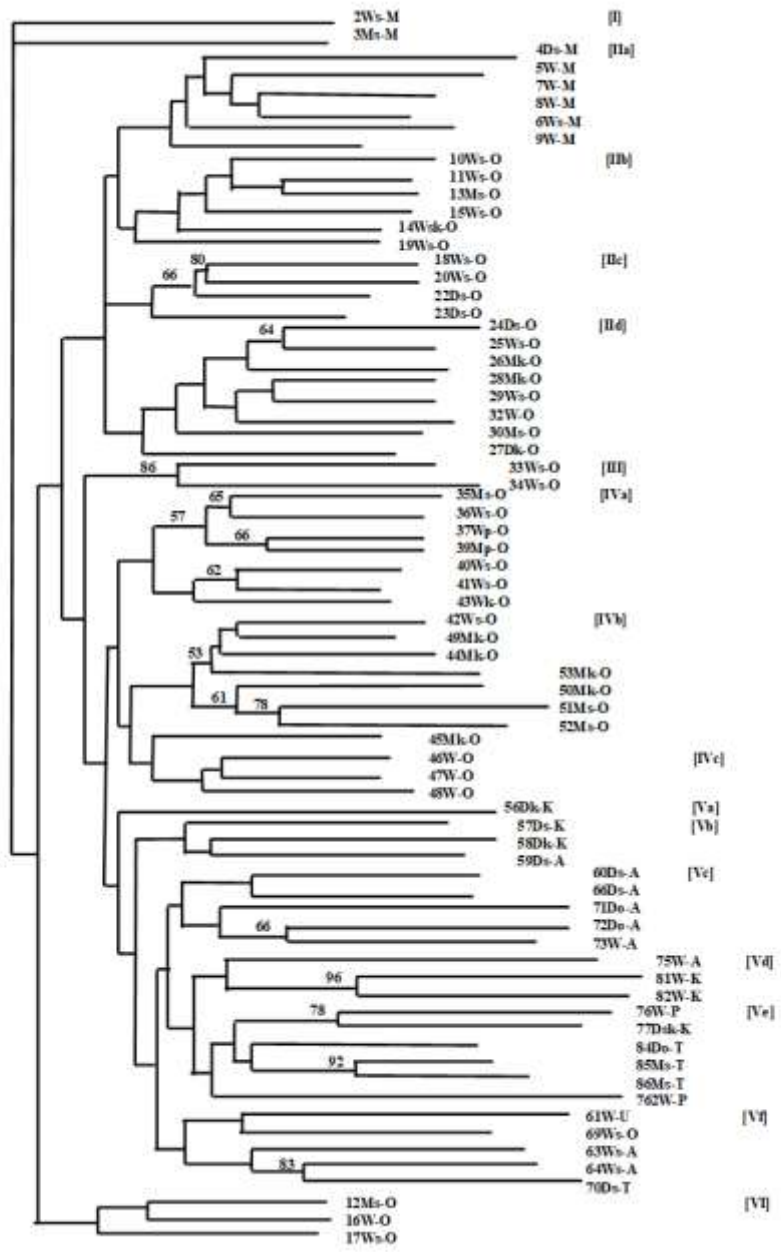

Figure 39. Dendrogram of neighbor-joining method based on AFLP markers of *S. pumila.*

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

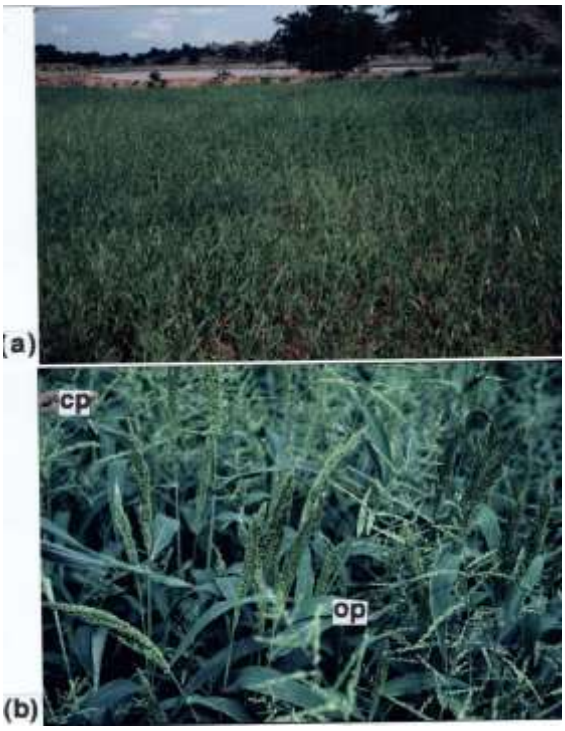

Figure 40. ***Brachiaria ramose***

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

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 agricultural complex. The agricultural complex is composed of their vernacular names, religious function, archaeological evidence, etc. The first author 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. 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.

People have cooked many types of food using millets and cereals. Mainly *bhat* (*meshi* in Japanese), *roti* (*pan*), and *mudde* (*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 (Fig. 5a, 1st, 2nd, and 3rd from lower left). *Mudde* is a popular food made from cereal flour and originated from the cooking of *ugari* brought from Eastern Africa via the Arabian Peninsula. Figure 41 and Table 31 show 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) *mudde* and boiled grain made using *Brachiaria ramosa*; (e) *puli*; and (f) *idli*.

Table 31. 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.

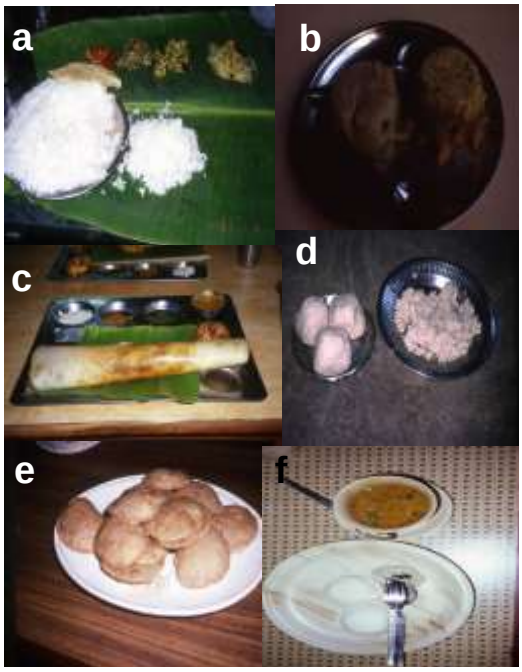

Figure. 41. Cookeries of cereal in the Indian subcontinent:

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

Sorghum bicolor and *Pennisetum glaucum* are mainly used for making *roti*, while *Eleusine coracana* is mostly used for making *mudde* and fermented alcoholic drink *chan* (Figure 43a, b, and c). Other millet species are mainly used for *bhat*. A special food, *mavu*, is made from the raw flour of *Setaria italica* and *Oryza sativa* as offering for gods and goddesses during festivals. Nine foods are made using *Brachiaria ramosa* (Figure 42a), *mudde* is made using *Eleusine coracana* (Figure 42c), and *chapati* is made using wheat, *Triticum aestivum* (Figure 42c and Figure 43d, upper). With respect to fermented foods, a starter is made from *Hordeum vulgare* (Figure 43a, starter; 43b, a jar for fermentation; 43c, alcohol drink, *chan*, made from *Eleusine coracana*; and 43d, yogurt, *dahi*.

Other cookeries are shown in Table 31, Figure 41 and Figure 42. *Upma* is a coarse-ground grain food (Figure 41b, right). *Dosa* is a thin leavened pancake stuffed with potato curry (Figure 41c). *Idli* is a leavened pound cake made using the same ingredients as *dosa* (Figure 41f). *Vada* is a cake made from freshly ground *dal* or millet flour. *Ganji* is a very thin starch-paste made from the same ingredients as *mudde*.

Figure 42. Cookeries of nine foods made from *Brachiaria ramose* (a);
b, *chapati* from wheat; c, *mudde* from *Eleusine coracana.*

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 gods and made only from foxtail millet and rice in Tamil Nadu.

Figure 43. Ferment food

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

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 (Table 32). 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).

Table 32. Vernacular names of Indian foods of made from cereals

Country	Grain			Meal grain	Flour/baked breads				/fried					/roasted	/steamed	/boiled			Raw flour	Alcoholic drink
	/boiled							/fermented					/fermented		/fermented	thick porridge	thin porridge	sweet		
State	chawal	pullao	biriyani	upma	chapati	roti	parautha	nan	puri	samosa	vada	murukku	dosa	tsuampa	idli	mude	ganji	kheer	mavu	
Pakistan																				
NWFP	*ghara* [6]					*shapik* [6]														
Gilgit	*chawal, gharaji* and *zibek* [6]					*tathui* and *roti* [6]														
Baltistan						*chakhor* [6]														
Punjab	chawli, *bat* [6]				chapati	roti		nan	puri	samosa						+		*kheer* [6]		
Baluchistan																				
India																				
Jammu & Kashimir	chawl																			
Himachal Pradesh	chawal, bhat				chapati	roti														
Uttar Pradesh					chapati	roti		nan												
(Uttaranchal)	bhat				chapati	roti			puri					bukkuna, bukani			bari	kheer, kheel, tasmai		
Punjab																				
Haryana	chawal, bhat																			
Rajasthan																				
Gujarat																				
Madhya Pradesh	bhat					roti											peja, pej	kheer		
Maharashtra	bhat, tandul	pilav, plao	biriyani		chapati	bhakar, roti		nan			wada				idli		ambil, ambli			
Bihar (Jharkhand)	bhat			dara		roti			puri									kheer		handia,
Orissa (Chattisgarh)	bhat	pulao	biriyani	upma	chapati	chakuli, roti			poori		vada	muruki	dosa		idly	onda	pejo, jau			
Andhra Pradesh	annamu			uppuma, uppittu	chapathi	roti			poori		vada	murukku	dosai		idly, idry	samkati, ambali	ganji	kheer		
Tamil Nadu	sadam, soru		biriyani	uppuma	chapathy	roti	parota		poori		vadai	murukku	dasai		idlai, idly	kali	kulu		mavu	
Karnataka	anna	pulau	biriyani	uppittu	chapati	roti	paratha	nan	puri, burugu	samosa	vada		dosa, dosai		idri	mude,mudde, muddi, mudii	ganji	kheer		
Kerala																				
Nepal	bhaat, bhat					roti								tsuampa		dhido, senne (Sherpa)				chan, chann, tompha, roxi, roksi
Bhutan																				
Bangradesh																				
SriLanka	batt																			

Italics cited from 6) Kawase (1991).

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 33. 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 33. 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 34. 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 34. 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 35. 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 35. Vernacular names of other indigenous millets and rice

Country / State / Growth habit	Language	Status	Vernacular names (Indigenous people)					
			Panicum sumatrense summer annual	*Paspalum scrobiculatum* perennial	*Echinochloa frumentacea* summer annual	*Digitaria cruciata* 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 same, sama, samuru, *nella shama* [4]					
		domest		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 36. 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 36. Vernacular names of Asian and African millets in Indian subcontinent

Country / State	Language	Status	Vernacular names (Indigenous people)				
			Panicum miliaceum	*Setaria italica*	*Eleusine coracana*	*Sorghum bicolor*	*Pennisetum glaucum*
Growth habit			summer annual	summer annual	summer annual	summer aannual	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* jangali-suau (Paraja) = *E. indica*	jowar	bajera
Orissa (Chattisgarh)	Orya	wild/weed					
			pani-varagu, cheena	kangu, gangu	ragi, manje-suau (Paraja), mandia (Kondho), pahado-mandia (Kond Dora)	jonna, jhna, jowary, jowar	kayna
		domest					
	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 37. *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 37. Vernacular names of other cereals in Indian subcontinent

Country State Growth habit	Language	Status	Vernacular names (Indigenous people) *Triticum aestivum* winter annual	 *Hordeum vulgare* winter annual	 *Avena sp.* winter annual	 *Zea mays* 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 33 and 34). 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 36and 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 38. 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 38. 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 39. 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 39. 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 Fig. 6. 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).

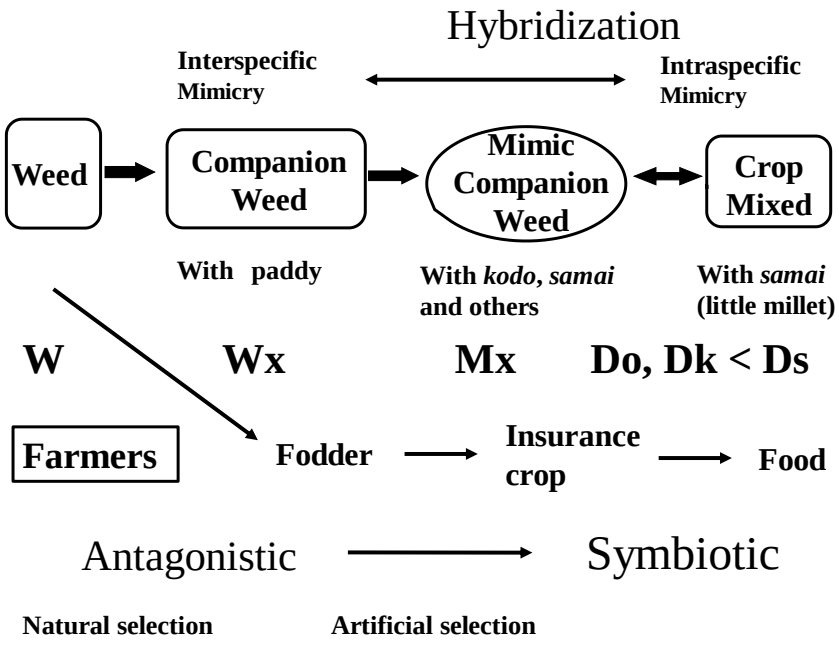

Figure 44. Domestication process of *S. pumila* in relation to the weed-crop complex.

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. 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 40. 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).

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. 45 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.

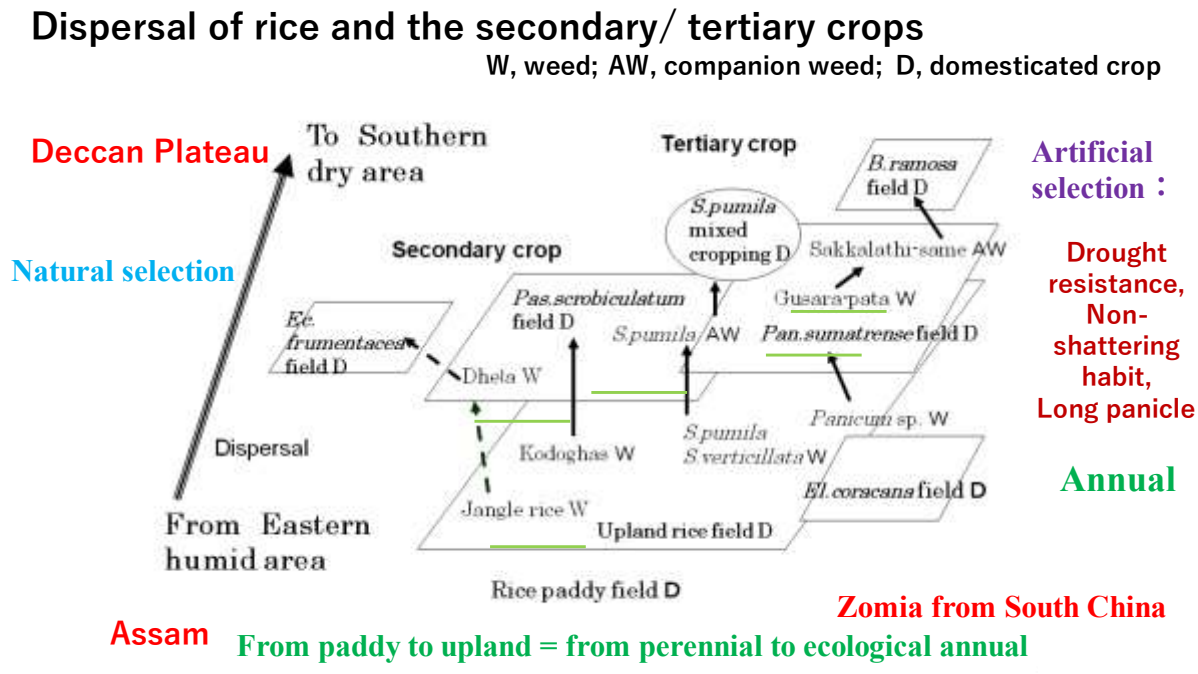

Figure 45. Domestication process of millets in the Indian subcontinent

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 45. 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.