Variation and distribution of

Setaria italica (L.) P. Beauv. and associated *Setaria* weeds

in northern Pakistan

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Contents

Chapter 1: Introduction

Setaria italica (L.) P. Beauv. (foxtail millet) is a summer annual cereal crop. It has been cultivated since the beginning of agriculture, and is distributed widely over Eurasia from Europe to East Asia, including island parts of Southeast Asia.

It has been experimentally proven that the ancestor of *S. italica* is probably *S. viridis* (L.) P. Beauv., the wild relative. Both *S. italica* and *S. viridis* are diploid (2n=18) species. Kihara and Kishimoto (1942) and Li et al. (1942) reported that the F_1 hybrid between them showed regular chromosome pairing of nine bivalents at MI and normal fertility.

On the other hand, little is known about the geographical origin of *S. italica*. Since *S. viridis* is widely distributed across the warm temperate regions of Eurasia, ranging from Europe to East Asia including a northern part of Africa (Lazarides 1980, Townsend et al. 1968, Clayton 1980, Maire et al. 1952 and Cope 1982), the distribution of the living plants contributes very little to the clarification of the geographical origin of *S. italica*.

Archeological remains of *S. italica* were found in several places in Eurasia (Zohary and Hopf 1988). Carbonized seeds of *S. italica* first appeared in the second millennium BC at Bronze Age settlements in central Europe and France. In northern China, *S. italica* was found in the

Neolithic Yang Shao farming villages (4000 BC). Therefore, both single and multiple origins of *S. italica* were proposed. Vavilov (1992) reported that the center of diversity of *S. italica* is located in eastern Asia including China and Japan. Nakao (1966) regarded the northwestern part of India as the place of domestication. According to Sakamoto (1987a), *S. italica* was first domesticated within the area ranging from Afghanistan to India. Independent domestication of *S. italica* both in China and Europe was suggested by Harlan (1992). De Wet et al. (1979) assumed that it has been introduced into cultivation at several places across Eurasia.

In recent years, cultivation of *S. italica* rapidly declined because of its low economic value as compared to major crops such as rice, wheat and maize. However, it is still grown in various locations across Eurasia mainly for self consumption. Because of the lack of modern breeding efforts and systematic introduction of the improved varieties, *S. italica* collected from local areas can be regarded as endemic landraces, and are suitable materials for the study of phylogenetic differentiation of this crop.

Landraces of *S. italica* showed wide variation in many characters, including heading response (Takei and Sakamoto 1987 and 1989), number of tillers (Takei et al. 1981, Sakamoto 1987b), phenol color reaction (Kawase and Sakamoto 1982) and amylose content of endosperm starch (Takei et al. 1989). Prasada Rao et al. (1987) recognized three races of

S. italica, moharia, maxima and *indica*, based on their morphological variation; these races were distributed in Europe and southwestern Asia, in Transcaucasia and in India and the rest of southern Asia, respectively.

In many cases, local people maintained landraces of *S. italica* identified by their own local names (Takei 1989, Kawase et al. 1995), agricultural practices (Nakui 1991, Takei 1994, Tachibana 1995), utilization methods (Kimata et al. 1986, Kimata 1991) and rituals and ceremonies (Ono 1960, Mabuchi 1988). Such ethnobotanical information should be taken into consideration to understand the differentiation of *S. italica*.

Associated *Setaria* weed forms have been found in *S. italica* fields and their surroundings (Tsvelev 1976, Kobayashi 1988, Ochiai 1996a). The associated form is morphologically similar to *S. italica*, but has a shattering habit identical to *S. viridis*. On the other hand, natural hybrids between *S. italica* and *S. viridis* were observed in the areas where their distribution overlapped (Darmency et al. 1987). Relationships among *S. italica*, *S. viridis* and the associated *Setaria* weed form seem complicated. The origin of this weed form and its role in domestication and differentiation of *S. italica* is still under debate.

It is important to elucidate the phylogenetic differentiation of *S. italica* in northern Pakistan between Afghanistan and India. Schibe (1943) and Nakao et al. (1965) have reported the wide variation of *S. italica* grown in northern Afghanistan and in Pakistan. Sakamoto (1987b) pointed out that *S. italica* grown in Afghanistan retained rather primitive features. A study on hybrid pollen sterility (Kawase and Sakamoto 1987) indicated that genetically less specialized landrace groups are distributed in the area ranging from Afghanistan to India.

In 1987 landraces of *S. italica* were first systematically collected in the mountain areas of northern Pakistan by the Kyoto University Scientific Expedition to the Indian Subcontinent (Sakamoto 1989). This field expedition was carried out in an area of northern Pakistan ranging from the eastern end of the Hindu Kush to the western end of the Karakoram (Fig. 1), and 74 samples of *S. italica*, 51 of *S. viridis* and nine of unidentified *Setaria* samples were collected. Collection sites of plant samples were the North Western Frontier Province (N.W.F.P.), Gilgit Agency and Baltistan. The Gilgit Agency and Baltistan are disputed areas between Pakistan and India, but situated on the Pakistan side of the cease-fire line.

In the present study, the variation and distribution of *S. italica* in northern Pakistan are clarified in chapter 2. Then, the grouping of landraces is attempted based on the tillering characters identified in chapter 3. Furthermore, the characteristics of the unidentified *Setaria* samples collected at two villages in northern Pakistan were compared to each other. Finally, the domestication and differentiation process of *S. italica*, and origin of

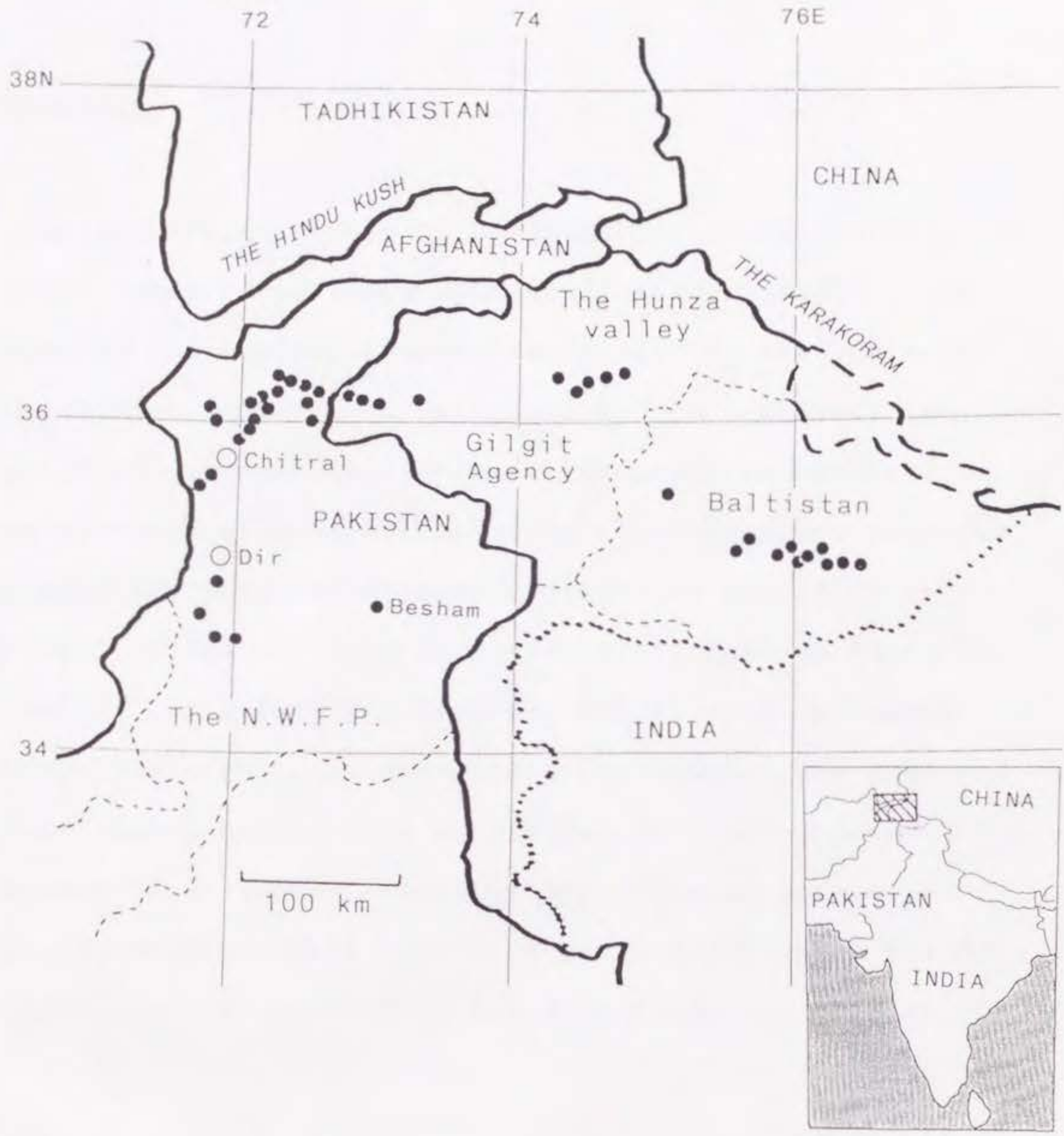

Fig. 1. Collection sites of *Setaria italica* in northern Pakistan.
● :Collection site
—— :International boundaries
····· :Cease-fire line
- - - :Claimed by India under Chinese administration
----- :State and divisional boundaries.

associated *Setaria* weeds in northern Pakistan are discussed.

Chapter 2: Characteristics and distribution of three landrace groups of *S. italica* in northern Pakistan

INTRODUCTION

S. italica continues to be grown in remote villages in mountain areas of northern Pakistan (Sakamoto 1989). The purpose of the present chapter is to clarify the variation of *S. italica* in northern Pakistan, and to elucidate the relationship between the northern Pakistani strains and other Eurasian strains by comparing the characters observed from seedling stage to maturity (Ochiai et al. 1994). In addition, pollen and seed fertility of F_1 hybrids among the *S. italica* collected from northern Pakistan is estimated. Northern Pakistan is an ethnologically complicated area and several ethnic groups have cultivated *S. italica* under different local names. Finally, the characteristics and geographical distribution of *S. italica* in northern Pakistan are discussed in relation to the ethnobotanical information.

MATERIALS AND METHODS

Analysis of characters

Plant materials used in the present chapter were 74 strains of *S. italica* collected in northern Pakistan (Table

1). Seventy strains of *S. italica* from the seven areas of Eurasia were also used for comparison (Table 2).

Characters observed at each growth stage were as follows:

1). Seedling characters: germination rate; anthocyan pigmentation on seedlings.

2). Characters at the vegetative stage: number of days to heading; number of leaves on the main culm; number of effective tillers including the main culm.

3). Panicle characters: panicle length and width; panicle type: short-conical, conical, long-conical, cylindrical or top-branched; bristleness: long, medium or short; anther color: orange or white; shattering type: non-shattering or shattering.

4). Grain characters: color of lemma and palea: yellow, pale-yellow, orange or brown; surface of lemma and palea: lucid or non-lucid; grain length (L) and width (W) and their product (LxW) and ratio (L/W); thousand grain weight; waxiness of endosperm starch; phenol color reaction of lemma and palea.

All the strains were sown on May 21, 1991 in wooden nursery boxes filled with sterilized soil. One month later, five seedlings per strain were transplanted to cultivation beds in glasshouses in Kyoto, Japan at 35°N latitude. They were grown without temperature or daylength control.

Waxiness of endosperm starch was determined by staining with an iodine iodine-potassium (I-KI) solution. Phenol

Table 1. *S. italica* samples collected from northern Pakistan

Collection area	Collection number	Collection area	Collection number
Dir and Besham and	87-9-20-6-1	The western part of	87-9-28-1-1
neigboring areas	87-9-21-1-1	Gilgit Agency	87-9-28-1-2
(6 samples)	87-9-21-5-1	(5 samples)	87-9-28-2-1
	87-9-22-4-1		87-9-28-3-1
	87-10-26-1-1		87-9-28-6-1
	87-10-26-1-2		
Chitral District,	87-9-24-2-2	The Hunza valley,	87-10-2-2-1
N.W.F.P.	87-9-24-3-2	the eastern part of	87-10-2-2-2
(32 samples)	87-9-25-2-1	Gilgit Agency	87-10-2-3-1
	87-9-25-2-2	(6 samples)	87-10-2-4-1
	87-9-25-5-1		87-10-2-6-3*
	87-9-25-5-2		87-10-4-1-1*
	87-9-26-2-1		
	87-9-26-2-2	Baltistan	87-10-6-2-1
	87-9-26-3-1	(25 samples)	87-10-6-2-2
	87-9-26-3-2		87-10-8-1-1
	87-9-26-3-3		87-10-8-1-2
	87-9-26-5-1		87-10-8-2-1
	87-9-26-6-3		87-10-8-3-1
	87-9-26-6-4		87-10-8-3-2
	87-9-26-7-1		87-10-8-4-1
	87-9-26-7-2		87-10-8-4-2
	87-9-26-8-1		87-10-8-4-4
	87-9-26-8-2		87-10-8-4-5
	87-9-26-9-1		87-10-8-5-1
	87-9-26-9-2		87-10-8-5-2
	87-9-26-10-1		87-10-8-5-3
	87-9-26-10-2		87-10-8-5-4
	87-9-26-11-2		87-10-8-5-5
	87-9-27-1-3		87-10-9-2-1
	87-9-27-3-1		87-10-9-3-1
	87-9-27-3-1		87-10-9-3-2
	87-9-27-3-2		87-10-9-4-1
	87-9-27-5-1		87-10-9-4-2
	87-9-27-5-2		87-10-9-4-3
	87-9-27-6-1		87-10-9-4-4
	87-9-27-6-2		87-10-19-1-1
	87-9-27-7-2		87-10-20-1-1*
		Total 74 samples	

*: Not investigated.

Table 2. *S. italica* strains from seven areas of Eurasia

Collection number	Locality	Collection number	Locality
Europe (9 samples)		K87-10-1-3-1	India
80-10-9-2-1	France	K87-10-6-7-1	India
79-5-4-6	Germany[1)]	K87-10-11-6-1	India
75-7-7-1	Belgium[2)]	K87-10-12-9-2	India
79-8-10-1	Spain	K87-10-11-6-2	India
89-3-3-1	Portugal	K87-10-11-6-3	India
75-8-1	Czechoslovakia[3)]	75-10-7-3	Nepal
83-4-12-121	Yugoslavia[4)]	75-10-9-1	Nepal
83-4-12-118	Bulgaria[4)]	84-5-12-5	Nepal
83-4-12-119	Hungary[4)]	90-3-7-1	Bhutan
		83-5-9-1	Bangladesh
Central Asia (5 samples)		83-5-9-3	Bangladesh
74-9-21-3	Dagestan[4)]	86-6-10-1	Bangladesh
74-9-21-4	Kirghizia[4)]		
74-9-21-6	Uzbekistan[4)]	Southeast Asia (7 samples)	
74-9-21-7	Georgia[4)]	83-8-5-46	Myanmar
74-9-21-9	Ukraine[4)]	83-8-5-54	Myanmar
		75-2-12-2	Thailand
Afghanistan (7 samples)		76-12-9-1	Indonesia
SGK-14	Afghanistan	81-6-10-1	Indonesia
SGK-26	Afghanistan	73-4-3	The Philippines
SGK-77	Afghanistan	77-10-7-29	The Philippines
SGK-95	Afghanistan		
SGK-108	Afghanistan	East Asia (18 samples)	
SGK-341	Afghanistan	72-8-1-1	Taiwan
SGK-368	Afghanistan	72-8-8	Taiwan
		81-2-6-1	China
Southern Pakistan (5 samples)		81-2-6-2	China
IBPGR2544(1)	Punjab[5)]	80-5-4-2	China
IBPGR2544(2)	Punjab[5)]	83-3-17-1	China
IBPGR2559(1)	Punjab[5)]	77-12-1-1	Korea
IBPGR2569(3)	Punjab[5)]	77-12-12-4	Korea
IBPGR2583(6)	Baluchistan[5)]	78-11-8-1	Korea
		78-11-14-8	Korea
South Asia (19 samples)		79-4-3-1	Japan
85-10-16-2-2	India	78-8-26-1	Japan
85-10-16-5-2	India	72-10-20-4	Japan
85-10-23-1-4	India	72-10-7-4	Japan
85-10-27-3-15	India	72-10-8-8	Japan
85-11-1-2-13	India	72-10-10-15	Japan
85-11-10-1-2	India	73-7-29-4	Japan
(Continued)		86-4-14-8	Japan
		Total 70 samples	

1)A strain obtained from Karl Marx Universitat, Leipzig, Germany.
2)A strain obtained from Dienst Voor Parken En Plantsonen, Antwerpen, Belgium.
3)A strain obtained from the Institute of Genetic Plant Breeding, Prague-Rilzyne, Czechoslovakia.

4)Strains obtained from the N.I. Vavilov All Union Institute of Plant Industry, Leningrad, USSR.
5)Strains obtained from the National Institute of Agrobiological Resources, Tsukuba, Japan.

color reaction was examined as follows. Ten mature grains with lemma and palea were soaked in 2 ml of 3% phenol (hydroxybenzene) solution for 24 hours at room temperature. After gentle drying, the color of lemma and palea was observed. If the surface was stained blackish brown, the reaction was judged as positive. If the surface was not stained, the reaction was judged as negative.

Pollen and seed fertility of F_1 hybrids

The strains used for evaluation of pollen and seed fertility of F_1 hybrids were three from Chitral District (C1: 87-9-26-6-3, C3: 87-9-26-2-2 and C4: 87-9-26-9-2), one from the western part of Gilgit Agency (C2: 87-9-28-1-1), one from the Hunza valley (B2: 87-10-2-3-1) and two from Baltistan (B1: 87-10-8-4-4 and B3: 87-10-9-3-1). The strains with anthocyan pigmentation on their seedlings (C3, C4, B2 and B3) were used as male (pollen) parents, and those lacking pigmentation (C1, C2 and B1) were used as female parents.

Parental strains were artificially pollinated during anthesis. Emasculation was carried out just before the dehiscence by removing the anthers with forceps or vacuuming the anthers by an air pump with a micro-nozzle. Then, the pollen of male parents were smeared on the pistil of the female parent. If the seedlings obtained showed anthocyan pigmentation, they could be identified as F_1 hybrids between the parental strains, because anthocyan pigmentation is dominant in *S. italica*.

Pollen and seed fertility were estimated as follows. The F_1 hybrids and their parental strains were sown on May 23, 1995 and were grown in a glasshouse. Pollen grains of each of the F_1 hybrids and their parental strains were collected by packing whole panicles in paper bags during anthesis, and were stained by glycerine carmine solution on glass slides. The pollen fertility was calculated from the frequency of normally stained pollen grains among at least three hundred pollen grains observed for each of the F_1 hybrids and its parental strains. The seed fertility was the percentage of fully ripened grain among at least one hundred and fifty spikelets randomly chosen from the self-pollinated and open-pollinated panicles.

RESULTS

Analysis of characters in *S. italica* from northern Pakistan

Of 74 strains of *S. italica* from northern Pakistan, one strain from Baltistan (87-10-20-1-1) did not germinate, and seedlings of two strains from the Hunza valley (87-10-2-6-3 and 87-10-4-1-1) died before transplantation. Measurement of characters could be carried out on 71 strains.

Tables 3, 4 and 5 compare the characters of *S. italica* form northern Pakistan and Eurasia. By combination of characters, the 71 strains of *S. italica* from northern Pakistan were divided into three groups: the Chitral group, the Baltistan group and the Dir group, which were named after the main areas where they are grown. The Chitral group consisted of 32 strains from Chitral District in N.W.F.P. (87-9-24-2-2 to 87-9-27-7-2 in Table 1) and 5 strains from the western part of Gilgit Agency (87-9-28-1-1 to 87-9-28-6-1). The Baltistan group consisted of four strains from the Hunza valley (87-10-2-2-1 to 87-10-2-4-1) and 24 strains from Baltistan (87-10-6-2-1 to 87-10-19-1-1). The Dir group included 6 strains collected from Dir and Besham and neighboring areas of N.W.F.P. (87-9-20-6-1 to 87-9-22-4-1, 87-10-26-1-1 and 87-10-26-1-2).

1). Seedling characters

Seventy one strains of *S. italica* from northern Pakistan had a high germination rate (mean: 96.7%) and grew

Table 3. Seedling characters and characters at the vegetative stage of *S. italica* from northern Pakistan and Eurasia

Characters / Areas	Frequency of strains with anthocyan pigmentation(%)	Number of days to heading		Number of leaves		Plant height (cm)		Number of tillers	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chitral Dist.	34.4	46.7	4.37	7.7	0.63	20.0	7.36	21.8	24.42
Western Gilgit	20.0	46.4	1.25	6.5	0.59	16.0	2.24	24.1	11.66
Hunza valley	100.0	44.7	4.26	8.6	0.77	31.0	14.56	1.0	0.00
Baltistan	58.5	45.2	4.04	8.0	0.43	38.5	9.00	1.4	0.57
Dir & Besham	0.0	86.3	22.28	15.1	6.89	92.1	57.49	28.9	17.19
Europe	30.0	48.4	6.01	7.7	0.91	28.7	19.00	7.7	6.75
Central Asia	60.0	54.3	10.44	10.5	3.75	54.4	55.56	7.5	4.96
Afghanistan	28.6	48.8	4.66	7.9	0.32	16.0	3.98	24.1	9.10
South Pakistan	40.0	70.4	7.69	12.7	1.44	81.9	12.70	3.4	1.35
South Asia	15.8	101.6	24.08	21.9	6.44	166.9	54.28	4.6	5.15
Southeast Asia	14.3	105.2	23.33	22.4	5.39	172.3	46.62	2.9	2.29
East Asia	44.4	89.3	22.03	19.7	6.17	155.9	59.12	2.9	3.41

Table 4. Panicle characters of *S. italica* from northern Pakistan and Eurasia

Characters	Panicle				Panicle type 1)	Anther color 2)	Bristle -ness 3)
	length(cm)		width(cm)				
Areas	Mean	SD	Mean	SD			
Chitral Dist.	2.5	0.86	0.8	0.13	SC	O	L
Western Gilgit	2.2	0.23	0.7	0.05	SC	O	L
Hunza valley	3.6	1.38	0.9	0.17	CO	W	S
Baltistan	3.1	1.22	0.9	0.17	CO	W	S
Dir & Besham	15.1	9.79	1.2	0.46	LC	O	L
Europe	3.0	2.52	0.8	0.33	SC	O	S
Central Asia	10.2	11.36	1.2	0.88	SC/CL	O	S
Afghanistan	1.9	0.45	0.7	0.11	SC	O	L
South Pakistan	16.0	3.65	1.1	0.14	CO/LC	O	S/M
South Asia	18.9	6.14	2.0	0.80	LC/CO/CL	O	S
Southeast Asia	24.0	8.01	2.0	0.57	CL/CO/TB	O	S
East Asia	22.1	8.97	2.4	0.72	CL/CO/TB	O/W	S

1) SC, CO, LC, CL and TB indicate short-conical, conical, long-conical, cylindrical and top-branched panicle, respectively.
2) O and W indicate orange and white colored anthers, respectively.
3) S, M and L indicate short, medium and long bristles, respectively.

Table 5. Grain characters of *S. italica* from northern Pakistan and Eurasia

Characters / Areas	Grain length(L) (mm) Mean	SD	Grain width(W) (mm) Mean	SD	LxW Mean	SD	L/W Mean	SD
Chitral Dist.	2.64	0.10	1.57	0.06	4.14	0.28	1.69	0.06
Western Gilgit	2.65	0.10	1.57	0.04	4.15	0.10	1.72	0.12
Hunza valley	2.29	0.09	1.66	0.02	3.80	0.20	1.35	0.05
Baltistan	2.35	0.10	1.76	0.11	4.13	0.35	1.35	0.12
Dir & Besham	2.56	0.09	1.51	0.03	3.83	0.21	1.70	0.00
Europe	2.39	0.13	1.63	0.11	3.87	0.26	1.50	0.12
Central Asia	2.32	0.19	1.56	0.10	3.61	1.48	1.50	0.06
Afghanistan	2.57	0.15	1.61	0.05	4.13	0.34	1.58	0.68
South Pakistan	2.48	0.10	1.55	0.13	3.83	0.27	1.64	0.16
South Asia	2.12	0.20	1.45	0.12	3.09	0.50	1.45	0.12
Southeast Asia	1.88	0.08	1.27	0.07	2.40	0.21	1.50	0.08
East Asia	2.05	0.16	1.46	0.07	3.00	0.29	1.40	0.09

Characters / Areas	Color of lemma and palea1)	Surface of lemma and palea2)	Thousand grain weight(g) Mean	SD	Waxiness of endosperm starch 3)	Frequency of strains with positive phenol color reaction (%)
Chitral Dist.	Y/PY	L	2.64	0.17	N	0.0
Western Gilgit	Y/PY	L	2.64	0.04	N	0.0
Hunza valley	Y/PY	NL	2.73	0.18	N	0.0
Baltistan	Y/PY	NL	2.80	0.34	N	5.0
Dir & Besham	Y/PY	L	2.33	0.10	N	33.3
Europe	Y/O	L	2.53	0.28	N	12.5
Central Asia	Y/O	L	2.07	0.39	N	0.0
Afghanistan	Y	L	2.73	0.07	N	0.0
South Pakistan	Y/O/B	NL	2.38	0.30	N	20.0
South Asia	Y/O/B	NL	1.94	0.58	N	31.6
Southeast Asia	Y/O	NL	1.17	0.20	N/W	0.0
East Asia	Y/O	NL	1.77	0.23	N/W	11.7

1)Y, PY, O and B indicate yellow, pale-yellow, orange and brown colored lemma and palea, respectively.
2)L and NL indicate lucid and non-lucid lemma and palea, respectively.
3)N and W indicate non-waxy and waxy endosperm starch, respectively.

until maturity. The Chitral group contained seedlings with anthocyan pigmentation in low frequency. Seedlings with anthocyan pigmentation were frequently found among the Baltistan group. Particularly, all the strains of the Hunza valley had lightly pigmented seedlings. No seedlings with pigmentation could be found among the Dir group.

2). Characters at the vegetative stage

The Chitral and Baltistan groups were early heading (mean: 44.7 to 46.7 days) with a small number of leaves (6.5 to 8.6) on the main culm. Both the Chitral and Baltistan groups were short in plant height; however, the Baltistan group was slightly taller (31.0 and 38.5 cm) than the Chitral group (16.0 and 20.0 cm). On the other hand, the Dir group showed intermediate to late heading (86.3 days) and tall plant height (92.1 cm) with many leaves (15.1) on the main culm.

Wide variability in number of tillers was observed from one (the main culm) to 57.5 tillers in strains from northern Pakistan and Eurasia, as shown in Fig. 2. The Chitral group was characterized by a large number of tillers. Most strains of the Baltistan group had only one panicle and scarcely had tillers, in the marked contrast to the Chitral group. The five strains of the Dir group had many tillers, except for one strain (87-9-21-1-1) with a few tillers.

In the western regions of Eurasia ranging from Europe to Afghanistan, strains that was early heading (48.4 to 54.3

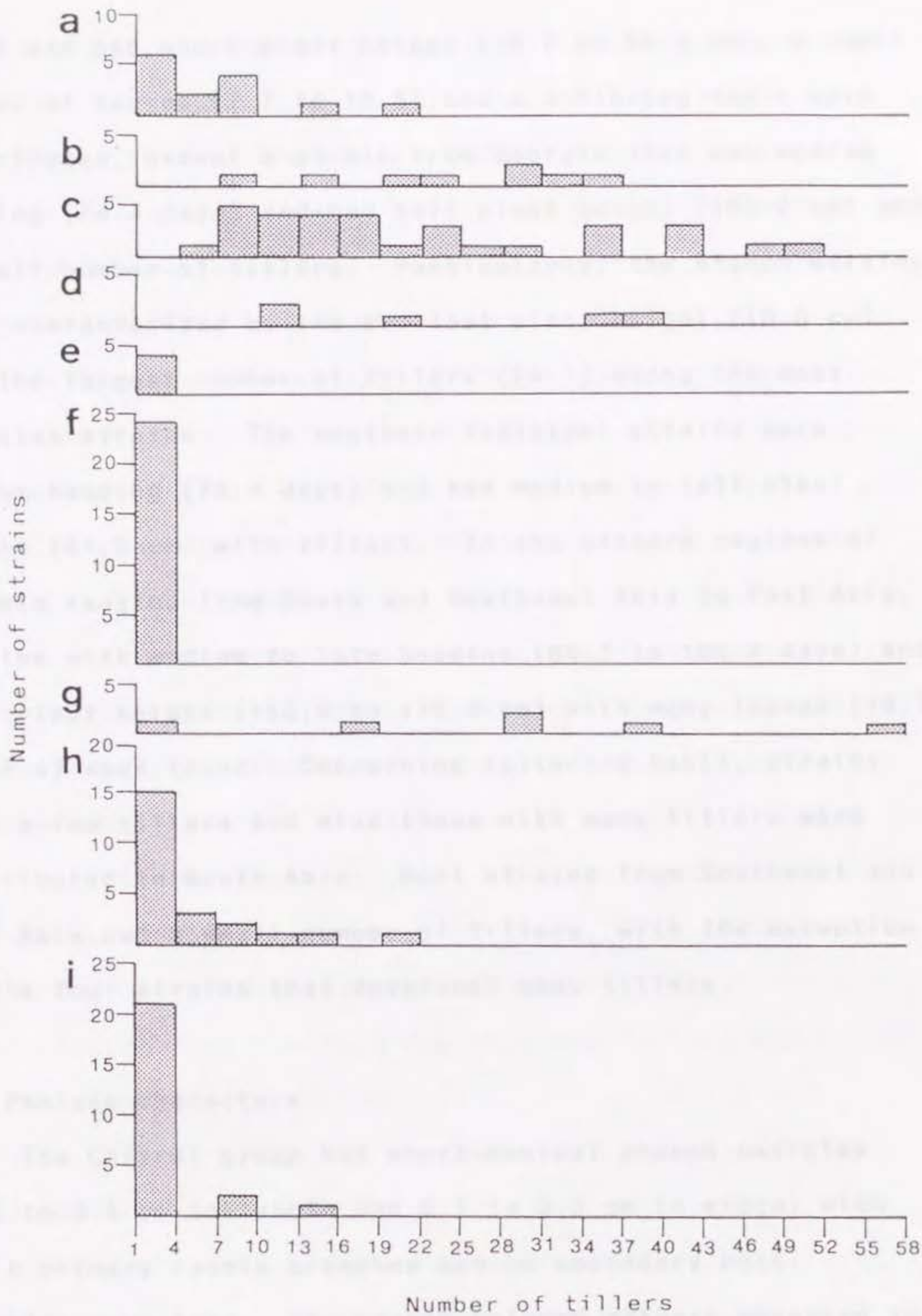

Fig. 2. Variability in number of tillers in *S. italica* from northern Pakistan and Eurasia.
a: Europe and Central Asia, b: Afghanistan, c: Chitral District, d: Western part of Gilgit Agency, e: Hunza valley, f: Baltistan, g: Dir and Besham and neighboring areas, h: Southern Pakistan and South Asia, i: Southeast Asia and East Asia.

days) and had short plant height (16.0 to 54.4 cm), a small number of leaves (7.7 to 10.5) and a tillering habit were distributed, except a strain from Georgia that was medium heading (74.4 days) and had tall plant height (165.2 cm) and a small number of tillers. Particularly, the Afghan strains were characterized by the shortest plant height (16.0 cm) and the largest number of tillers (24.1) among the west Eurasian strains. The southern Pakistani strains were medium heading (70.4 days) and had medium to tall plant height (81.9 cm) with tillers. In the eastern regions of Eurasia ranging from South and Southeast Asia to East Asia, strains with medium to late heading (89.3 to 105.2 days) and tall plant height (155.9 to 172.3 cm) with many leaves (19.7 to 22.4) were found. Concerning tillering habit, strains with a few tillers and also those with many tillers were distributed in South Asia. Most strains from Southeast and East Asia had a small number of tillers, with the exception of the four strains that developed many tillers.

3). Panicle characters

The Chitral group had short-conical shaped panicles (2.2 to 2.5 cm in length and 0.7 to 0.8 cm in width) with short primary rachis branches and no secondary ones. Bristles were long. The orange colored anthers observed in the Chitral group were frequently found in the Eurasian strains. Conical panicles with short bristles were observed in the Baltistan group. The white colored anthers of the

Baltistan group were rarely found in the Eurasian strains; they were seen only in four strains: one each from the Philippines, Taiwan, China and Japan. The Dir group had long-conical panicles (15.1 cm in length and 1.2 cm in width) with medium to long bristles. Anther color was orange.

The strains from Europe to Afghanistan had short and narrow short-conical shaped panicles, except a strain from Georgia which had a long and broad cylindrical panicle. The Afghan strains were distinguished from other west Eurasian strains by their long bristles. The Southern Pakistani strains were characterized by long-conical shaped panicles (16.0 cm in length, 1.1 cm in width) with bristles of short to medium length. The strains from eastern regions of Eurasia had long (18.9 to 24.0 cm) and broad (2.0 to 2.4 cm) panicles with developed rachis branches and short bristles.

Three strains of the Chitral group (87-9-25-2-2, 87-9-26-9-1 and 87-9-27-7-2) showed a shattering habit. All the other strains from northern Pakistan and Eurasia had a non-shattering habit.

4). Grain characters

Of the 71 strains from northern Pakistan, 69 strains had yellow or pale-yellow colored lemma and palea, and one each of the Chitral (87-9-25-2-2) and Dir (87-10-26-1-2) groups had brown ones. The strains with orange colored lemma and palea were widely distributed in Eurasia, except for northern Pakistan and Afghanistan. The surface of lemma and palea was lucid in the Chitral and Dir groups, while that of the Baltistan group was not.

The Chitral and Dir groups had long and narrow grains. On the other hand, the grains of the Baltistan group were short and broad. Fig. 3 shows the variability of the product (LxW) and the ratio (L/W) of grain length (L) and width (W) observed in the strains from northern Pakistan and Eurasia. The product and the ratio indicate the grain size and grain shape, respectively. The northern Pakistani strains were characterized by larger grains (LxW: 3.80 to 4.15) in comparison to the Eurasian strains (LxW: 2.40 to 3.87). The Chitral and Dir groups had elliptical grains (L/W: 1.69 to 1.72). In contrast, the Baltistan group had round grains (L/W: 1.35).

The strains from Europe and Central Asia had medium to large sized grains (LxW: 3.87 and 3.61). Large (LxW: 4.13) and elliptical (L/W: 1.50) grains with lucid lemma and palea were observed in the Afghan strains. The grains of the southern Pakistani strains were large (LxW: 3.83) and elliptical (L/W: 1.64). On the other hand, most strains from South, Southeast and East Asia had small (LxW: 2.40 to 3.09) and round (L/W: 1.40 to 1.50) grains with non-lucid lemma and palea.

The thousand grain weight of the northern Pakistani strains was heavy (2.33 to 2.80 g). This was also true of the strains from Europe, Afghanistan and southern Pakistan

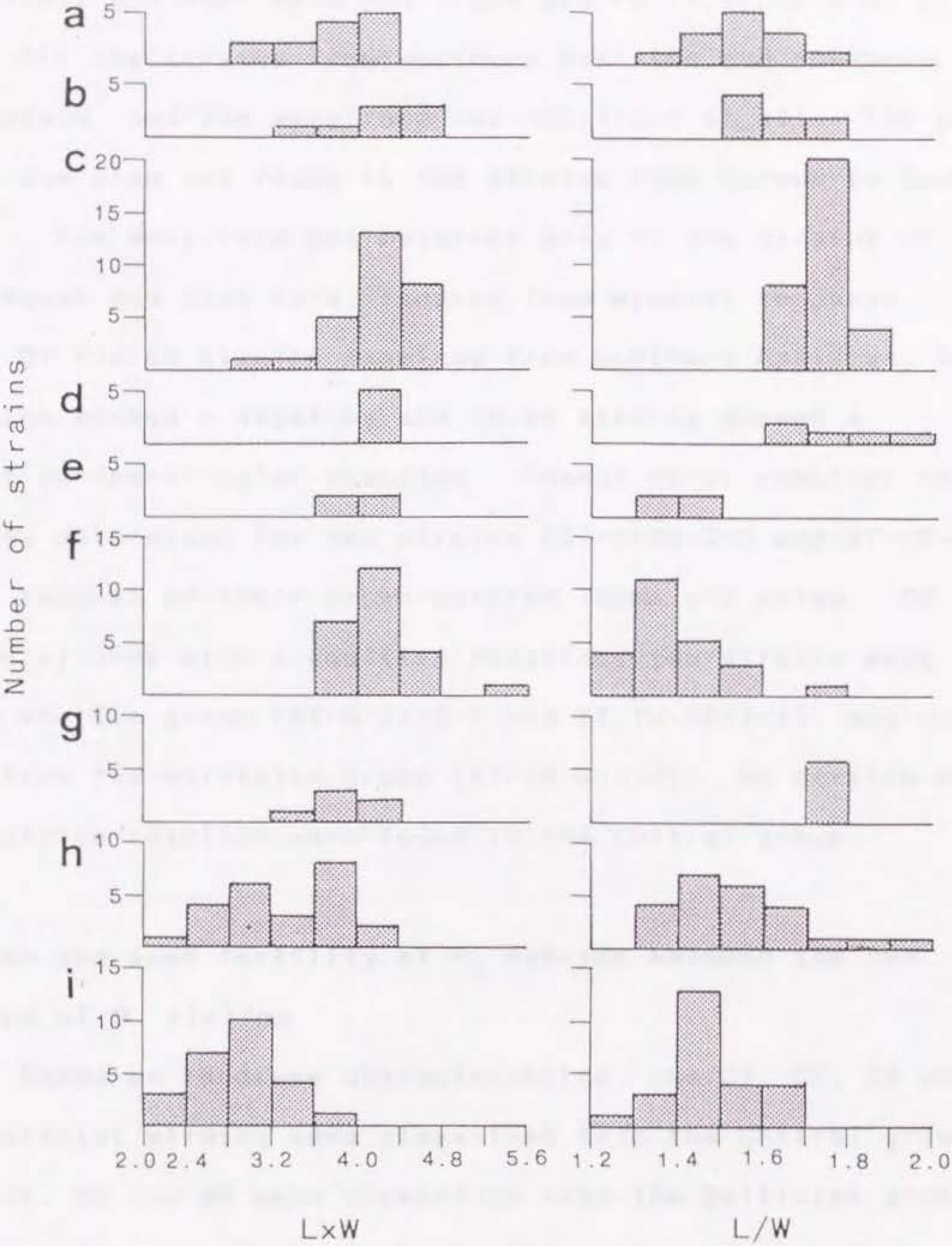

Fig. 3. Variability of the product (LxW) and the ratio (L/W) of grain length (L) and width (W) in *S. italica* from northern Pakistan and Eurasia.
a: Europe and Central Asia, b: Afghanistan, c: Chitral District, d: Western part of Gilgit Agency, e: Hunza valley, f: Baltistan, g: Dir and Besham and neighboring areas, h: Southern Pakistan and South Asia, i: Southeast Asia and East Asia.

(2.38 to 2.73 g). The strains from Central, South, Southeast and East Asia had light grains (1.17 to 2.07 g).

All the strains from northern Pakistan had non-waxy endosperm, and the waxy form was not found at all. The waxy form was also not found in the strains from Europe to South Asia. The waxy form was observed only in the strains of Southeast and East Asia, ranging from Myanmar to Japan.

Of the 65 strains examined from northern Pakistan, 60 strains showed a negative and three strains showed a positive phenol color reaction. Phenol color reaction could not be determined for two strains (87-9-25-2-2 and 87-10-26-1-2) because of their brown colored lemma and palea. Of the three strains with a positive reaction, two strains were from the Dir group (87-9-21-5-1 and 87-10-26-1-1), and one was from the Baltistan group (87-10-9-4-3). No strains with a positive reaction were found in the Chitral group.

Pollen and seed fertility of F_1 hybrids between the two groups of *S. italica*

Based on landrace characteristics, the C1, C2, C3 and C4 parental strains were classified into the Chitral group, and B1, B2 and B3 were classified into the Baltistan group. As summarized in Table 6, F_1 hybrids obtained from five cross combinations showed wide variation in pollen and seed fertility. The F_1 hybrids of the crosses C1xB3 and B1xC3 had high pollen and seed fertility, while that of B1xC4 showed subnormal fertility. On the other hand, the F_1

Table 6. Pollen and seed fertility of F_1 hybrids between the Chitral and Baltistan groups, and of their parental strains

Female parent Male parent[1)] F_1 hybrid	Fertility (%)		
	Pollen[2)]	Seed	
		Self	Open
C1 87-9-26-6-3	97.4 (+)	80.8	54.2
B3 87-10-9-3-1	97.1 (+)	84.4	—
F_1 95263	88.3 (+)	40.8	42.4
C2 87-9-28-1-1	96.6 (+)	57.2	56.6
B2 87-10-2-3-1	— (+)	73.4	62.4
F_1 95266	36.8 (-)	3.2	—
C2 87-9-28-1-1	96.6 (+)	57.2	56.6
B3 87-10-9-3-1	97.1 (+)	84.4	—
F_1 95267	33.1 (-)	0.5	0.0
B1 87-10-8-4-4	99.0 (+)	50.9	—
C3 87-9-26-2-2	98.7 (+)	67.7	51.2
F_1 95268	88.9 (+)	53.7	33.2
B1 87-10-8-4-4	99.0 (+)	50.9	—
C4 87-9-26-9-2	98.8 (+)	—	52.5
F_1 95269	65.9 (+)	36.9	6.0

1): C and B indicate the Chitral and Baltistan groups, respectively.
2): Dehiscence (+) or indehiscence (-) of anther.

hybrids of the crosses C2xB2 and C2xB3 showed indehiscence of anther, very low pollen fertility and set few seeds.

DISCUSSION

Landraces of *S. italica* collected in the mountain areas of northern Pakistan were classified into three groups based on a comparison of their characters: the Chitral, Baltistan and Dir groups. The characteristics of the three groups is summarized in Table 7. The three groups had such common characters as high frequency of strains with yellow or pale-yellow colored lemma and palea, large and heavy grains and non-waxy endosperm starch.

An obvious gap in the geographical distribution of the waxy form of *S. italica* was recognized between Nepal-India and Assam (Sakamoto 1982). Specially, the waxy form was isolated on the eastern side of this gap. Failure to find the waxy form in northern Pakistan supported this distribution pattern.

The strains of *S. italica* with a positive phenol color reaction were found in a rather limited region of Eurasia, while those with a negative reaction occurred in almost all the regions of Eurasia investigated (Kawase and Sakamoto 1982). It is suggested that a distributional gap in the frequency of positive phenotype lies between India and Afghanistan. In other words, positive phenotype was frequently found in the Indian strains but rarely found in the Afghan strains. In northern Pakistan between India and Afghanistan, the Chitral and Baltistan groups rarely contained strains with a positive reaction like the Afghan

Table 7. Characteristics of the Chitral, Baltistan and Dir groups from northern Pakistan

Characters	The Chitral group	The Baltistan group	The Dir group
Frequency of anthocyan pigmented seedlings	low	high	none
No. days to heading	short	short	long
Number of leaves	few	few	many
Plant height	very short	short	tall
Number of tillers	many	one	many
Panicle length	very short	short	long
Panicle width	very narrow	narrow	narrow
Panicle type	short-conical	conical	long-conical
Bristleness	long	short	short to medium
Anther color	orange	white	orange
Shape of grain	elliptical	round	elliptical
Surface of grain	lucid	non-lucid	lucid
Phenol color reaction	negative	negative	negative or positive

strains. However, both positive and negative types of strains were found among the Dir group.

Compared with other Eurasian strains, the three groups from northern Pakistan showed characters in common with the strains from different regions of Eurasia. The Chitral group was morphologically related to the strains of western regions of Eurasia ranging from Europe to Afghanistan. Both the Chitral group and the Afghan strains were particularly characterized by very short plant height, a large number of tillers, short-conical panicles with long bristles and large and elliptical grains with lucid lemma and palea. On the other hand, characters of the Baltistan group, i.e. a small number of tillers, short bristles, white colored anthers and round grains with non-lucid lemma and palea were also found in the strains of eastern regions of Eurasia ranging from South and Southeast Asia to East Asia.

The Dir group consisted of five strains with many tillers and one strain with a few tillers. The latter strain obtained as the market sample in Timergara, may have been brought into this area through the trade routes. The five strains of the Dir group with many tillers had characters in common with five of the southern Pakistani strains, namely medium to late heading, medium to tall plant height and a large number of long-conical panicles bearing medium to long bristles. These characters were also observed in the four strains from India: one each from Karnataka, Tamil Nadu, Andhara Pradesh and Maharashtra. It is suggested that the Dir group belongs to the typical landraces distributed from Pakistan to southern India.

As indicated in Fig. 4, the distribution areas of the Chitral, Baltistan and Dir groups were clearly isolated in northern Pakistan. The Chitral group was found in Chitral District, N.W.F.P. and the western part of Gilgit Agency. The Baltistan group was collected both in the Hunza valley, the eastern part of Gilgit Agency, and in Baltistan. The Dir group was sporadically found in Dir and Besham and neighboring areas, N.W.F.P.. It can be concluded that the three groups with their distinctive characters coexist separately in the mountain areas of northern Pakistan. However, there are no geographical barriers that block traffic over the distribution areas of these three groups. Also, the hybrid sterility that completely prevents hybridizations could not be found between the Chitral and Baltistan groups.

Based on the pollen and seed fertility of F_1 hybrids, it appeared that the Chitral and Baltistan groups are composed of genetically differentiated strains, despite their shared characteristics. The intraspecific pollen sterility between the Pakistani and the three tester strains indicated that the Pakistani landraces of *S. italica* have various phylogenetic backgrounds (Kawase et al. 1997). In conclusion, *S. italica* may have been introduced into northern Pakistan several times, and eventually formed the characteristic landrace groups.

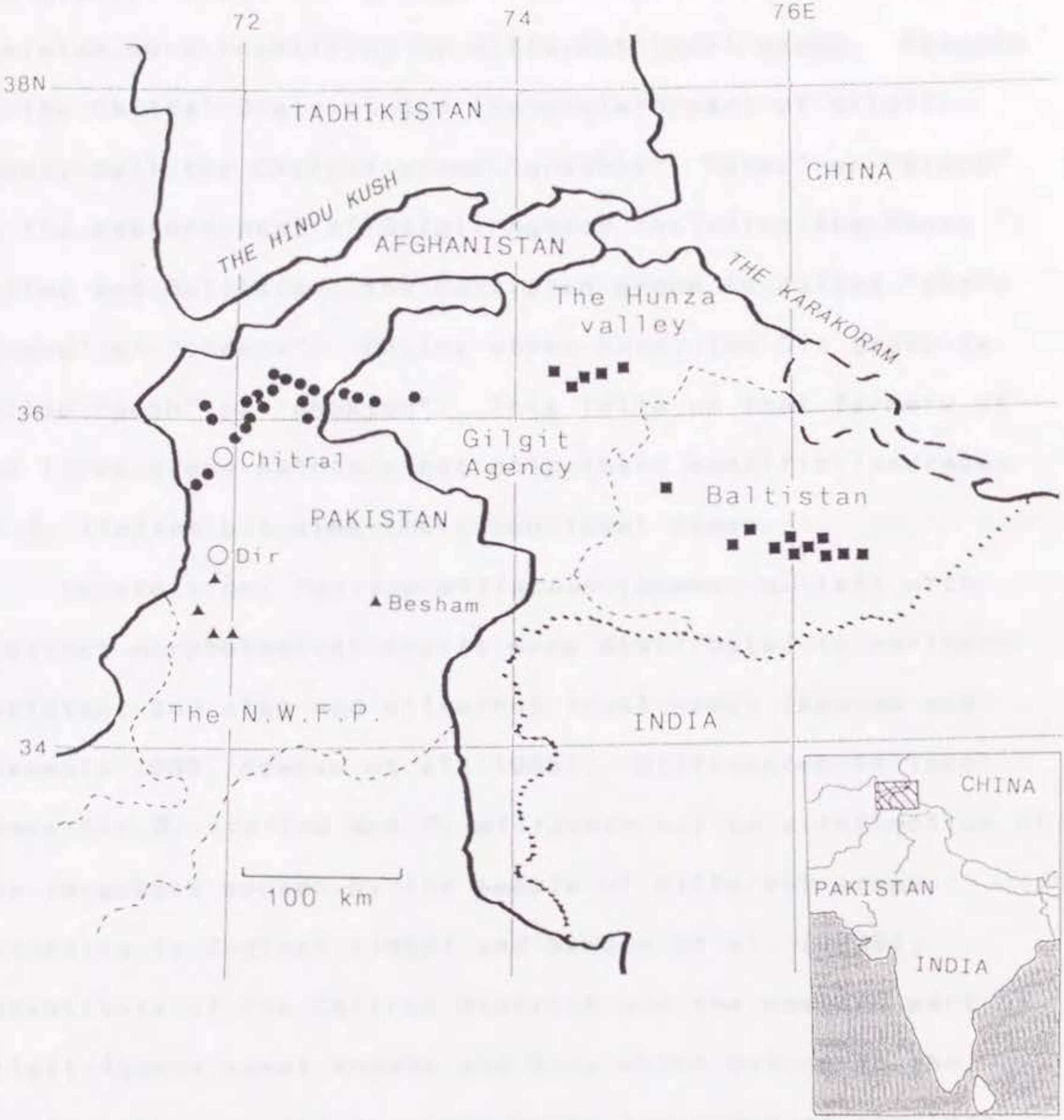

Fig. 4. The distribution areas of the Chitral (●), Baltistan (■) and Dir (▲) groups of *S. italica* in northern Pakistan.

According to Kawase and Sakamoto (1989) and Kawase et al. (1995), the three groups of *S. italica* from northern Pakistan were identified by different local names. Farmers in the Chitral District and the western part of Gilgit Agency call the Chitral group "grashik", "gras" or "grach". In the eastern part of Gilgit Agency including the Hunza valley and Baltistan, the Baltistan group is called "cha", "cheng" or "cheena". On the other hand, the Dir group is called "gogh" or "ghokton". This tells us that farmers of the three areas maintain not only their specific landraces of *S. italica* but also their own local names.

In addition, *Panicum miliaceum* (common millet) with distinct morphological traits were distributed in northern Pakistan, and also had different local names (Kawase and Sakamoto 1989, Kawase et al. 1995). Differences in local names for *S. italica* and *P. miliaceum* may be a reflection of the languages spoken by the people of different areas. According to Zograph (1982) and Kawase et al. (1995), inhabitants of the Chitral District and the western part of Gilgit Agency speak Khowar and Sina which belong to the Dardic language, and are Indo-Aryan languages of the Indo-European family, while, Balti, which is a member of the Sino-Tibetan language family, is used in Baltistan. In Dir and Besham and neighboring areas, the main language is Pashto, an Iranian language of the Indo-European family. Correspondence between the local names and the languages suggests a long history of utilization of *S. italica* and *P.*

miliaceum as the staple cereals in each area of northern Pakistan.

In the Hunza valley, people use two languages, Dumaki, one of the Dardic languages, and Bulushaski, an isolated language. The common local names for *S. italica* in the Hunza valley and Baltistan, in spite of the disagreement in spoken languages, suggests the introduction of local names of *S. italica* from Baltistan to the Hunza valley (Kawase et al. 1995).

In addition to the local names, agricultural practices and utilization methods of *S. italica* were conserved in each distribution area of the Chitral and Baltistan groups (Kawase and Sakamoto 1989, Kawase 1991). The Chitral group was cultivated admixed with *P. miliaceum* at nine collection sites. Both millets were harvested together by pulling off the whole plant, and were used together for cooking of boiled grain and unleavened bread. Farmers have not divided the Chitral group into local varieties. On the contrary, the Baltistan group was singly cultivated and was used for preparation of boiled grain, unleavened bread, tea, stew and sweets. Several local varieties of the Baltistan group which were referred to different local names were separately cultivated in each field. Local varieties of the Baltistan group were harvested by base-cutting and panicles were then cut off from the main culm.

It could be concluded that the present distribution of the three groups of *S. italica* depends not only on biological characteristics but also on ethnobotanical factors. Population with different ethnic backgrounds have maintained their own landrace groups of *S. italica* through identification, cultivation and utilization in mountain areas of northern Pakistan.

Chapter 3: Variation in tillering and its geographical distribution

INTRODUCTION

As revealed in chapter 2, *S. italica* from Eurasia displayed wide variation in the number of tillers, from only one (the main culm) to over 50. Particularly, both tillering and non-tillering types were separately distributed in northern Pakistan.

Such wide variation in the tillering habit of *S. italica* was reported by Ochiai (1996b), but it has not been found in other cereal crops. Several strains with a few tillers have been developed within modern breeding programs for major crops such as rice (Futsuhara and Yamaguchi 1963, Takamure and Kinoshita 1985), bread wheat (Atsmon and Jacobs 1977) and barley (Nonaka 1974). In contrast, *S. italica* landraces with a few tillers are the result of local selection by farmers using traditional agricultural practices over a long time.

In this chapter, tiller development is described for 16 strains chosen from the plant materials used in chapter 2. The three groups from northern Pakistan and the 70 strains from Eurasia are then grouped into four tillering types according to the observed tiller development patterns of the 16 strains. Finally, the geographical distribution of each tillering type is discussed.

MATERIALS AND METHODS

Observation of tiller development

Sixteen strains were selected for detailed analysis of tiller development to represent the full range of variation revealed in chapter 2 (Table 8). These strains were sown three times at one month intervals (April 21, May 19 and June 19) in 1992. One month later, five seedlings per strain were transplanted to a cultivation bed of a glasshouse in Kyoto, Japan at 35°N latitude. They were grown with a space of 14 cm between individual seedlings and 18 cm between rows without temperature or daylength control. The tiller development of one plant per strain was observed over an entire growth stage, from seedling stage to maturity. The following characters were recorded: number of days to heading; number of nodes on the main culm; position of each node producing primary tillers; number of primary, secondary and tertiary effective tillers; number of effective tillers of prophyll (the leaf without a leaf blade that developed at the first node of every tiller); and total number of effective tillers including the main culm.

Genetic analysis of tillering types

A cross experiment was carried out for genetic analysis of tillering types. Of the five parental strains listed in Table 9, three strains with anthocyan pigmentation were used as the male parent, and two strains without pigmentation

Table 8. *S. italica* strains used for observation of tiller development

Code number	Collection number	Locality
1	83-4-12-119	Hungary
2	74-9-21-7	Georgia
3	SGK14	Afghanistan
4	87-9-26-2-2	Chitral District, northern Pakistan
5	87-10-2-2-1	The Hunza valley, northern Pakistan
6	85-11-10-1-2	India
7	K87-10-11-6-3	India
8	75-10-9-1	Nepal
9	75-10-7-3	Nepal
10	75-2-12-2	Thailand
11	81-6-10-1	Indonesia
12	81-2-6-1	China
13	72-8-8	Taiwan
14	77-12-12-4	Korea
15	72-10-7-4	Japan
16	72-10-8-8	Japan

Table 9. *S. italica* strains used for genetic analysis of tillering types

Cultivation number	Collection number	Locality	Anthocyan pigmentation on seedlings*
95101	87-9-26-6-3	Chitral District, northern Pakistan	G
95102	83-4-12-119	Hungary	R
95104	72-8-8	Taiwan	R
95106	72-10-7-4	Japan	R
95107	72-10-8-8	Japan	G

*: R and G indicate seedlings with or without anthocyan pigmentation.

were used as the female parent. F_1 hybrids as well as their parental strains were sown on May 23, 1995, and were grown in the glasshouse. Tillering characters of F_1 hybrids and their parental strains were observed through the growth stage.

RESULTS

Observation of tiller development and classification of tillering types

Table 10 indicates the tillering characters of the 16 strains from Eurasia. Among the 16 strains, four patterns of tiller development, Types I - IV, were recognized and are summarized in Table 11. Different sowing times did not affect patterns of tiller development.

Among the four tillering types, Type I had the largest number of tillers. This type produced many primary tillers from the nodes on the main culm, which were widely dispersed from the third node from the bottom to the second node from the top, and also had secondary and tertiary tillers (Figs. 5 and 6). Tertiary tillers were last in the order of all the tiller development. Some Type I plants produced tillers from the node of the prophyll. The strains from Hungary (83-4-12-119) and Afghanistan (SGK 14) and the Chitral group of northern Pakistan (87-9-26-2-2) were recognized as Type I. The Type I strains used in the present study were early heading with a small number of nodes on the main culm, and developed a few leaves on the primary, secondary and tertiary tillers.

Type II had only one or two primary tillers that developed from the lower nodes of the main culm, i.e. the second to sixth node from the bottom, as shown in Figs. 5 and 6. No secondary and tertiary tillers were observed in

Table 10. Tillering characters of the 16 *S. italica* strains

Code No.	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers		Number of effective tillers			
			Lowest	Highest	Primary	2nd & 3rd	Prophyll	Total
1	59.0	12.5	4.0	10.5	5.0	5.5	4.0	15.5
2	77.3	16.3	—	—	0.0	—	—	1.0
3	56.7	11.7	4.3	10.7	7.3	15.0	0.7	24.0
4	61.7	12.7	3.0	11.0	7.3	15.7	0.7	24.7
5	56.0	9.7	—	—	0.0	—	—	1.0
6	124.3	27.0	5.0	5.0	0.3	0.0	0.0	1.3
7	144.3	30.0	—	—	0.0	—	—	1.0
8	72.5	20.0	5.0	6.0	1.0	0.0	0.0	1.5
9	95.7	21.0	—	—	0.0	—	—	1.0
10	128.3	21.0	2.0	3.0	0.7	0.0	0.0	1.3
11	67.5	16.5	—	—	0.0	—	—	1.0
12	140.0	26.3	—	—	0.0	—	—	1.0
13	71.0	17.5	3.5	4.5	2.0	0.0	0.0	3.0
14	103.0	24.7	—	—	0.0	—	—	1.0
15	98.3	19.3	—	—	0.0	—	—	1.0
16	136.0	23.5	4.0	8.5	5.0	3.0	0.0	9.0

Numerals indicate mean of three repeated cultivation.

Table 11. Characteristics of four tillering types of *S. italica*

Type	Number of days to heading	Number of leaves on main culm	Position of nodes with primary till: Lowest	Position of nodes with primary till: Highest	Number of effective tillers: Primary	Number of effective tillers: 2nd & 3rd	Number of effective tillers: Pro-phyll	Number of effective tillers: Total
Type I (n=8)								
Mean	59.1	12.3	3.8	10.8	6.8	12.9	1.5	22.1
SD	9.39	0.71	0.71	0.45	1.50	9.31	1.70	9.23
Range	48 - 73	11 - 13	3 - 5	10 - 11	4 - 8	5 - 31	0 - 5	15 - 41
Type II (n=5)								
Mean	85.4	21.0	3.8	4.6	1.6	0.0	0.0	2.6
SD	37.50	4.25	1.30	1.14	0.54	0.0	0.0	1.10
Range	55 - 122	15 - 26	2 - 5	3 - 6	1 - 2	—	—	2 - 3
Type III (n=23)								
Mean	97.2	20.7	—	—	0.0	—	0.0	1.0
SD	33.86	6.28	—	—	0.0	—	0.0	0.0
Range	40 - 155	9 - 32	—	—	—	—	—	—
Type IV (n=2)								
Mean	136.0	23.5	4.0	8.5	5.0	3.0	0.0	9.0

n: number of plants observed.

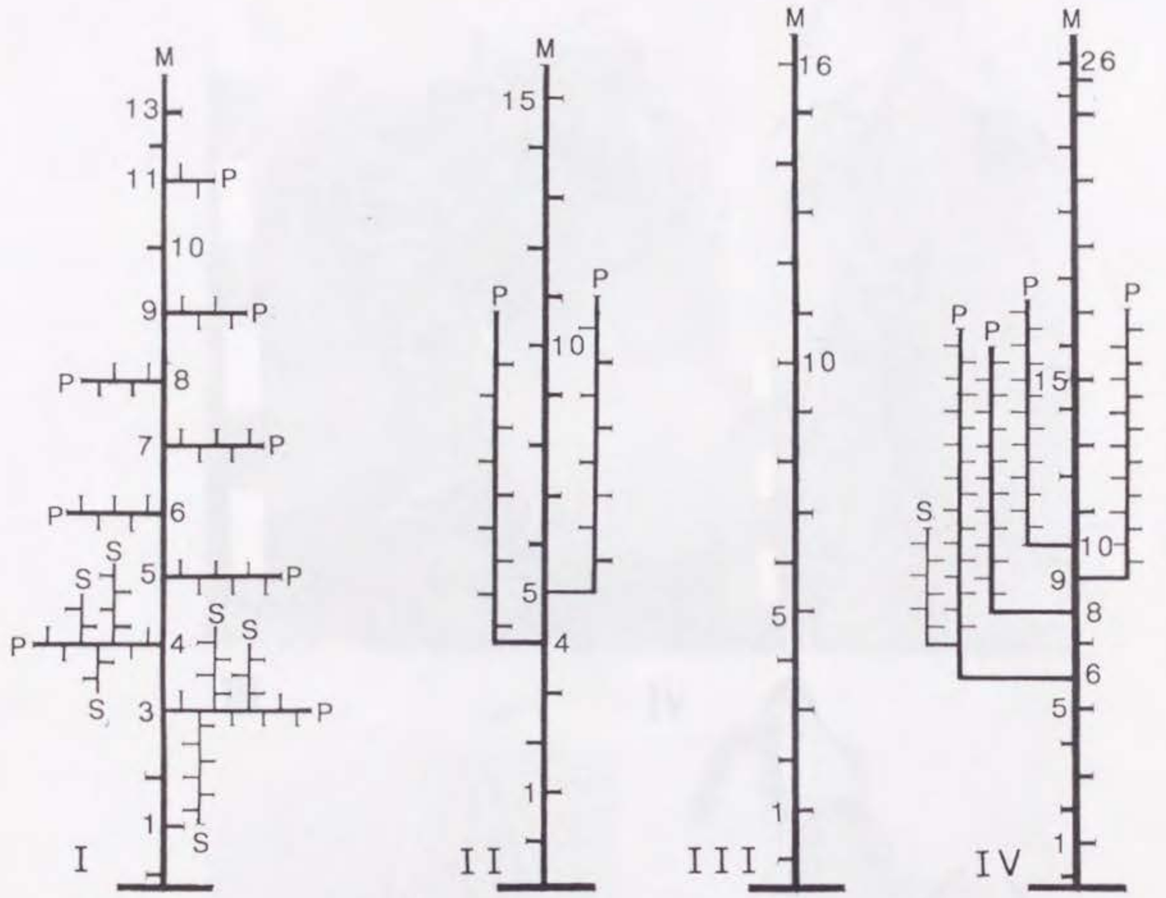

Fig. 5. Tiller development patterns of Types I, II, III and IV of *S. italica*.
Type I: the Chitral group of northern Pakistan, Type II: the strain from Taiwan, Type III: the strain from Indonesia, Type IV: the strain from Kochi Prefecture, Japan. M, P and S represent panicles of main culm, primary tillers and secondary tillers, respectively. Numerals indicate the position of the nodes on the main culm.

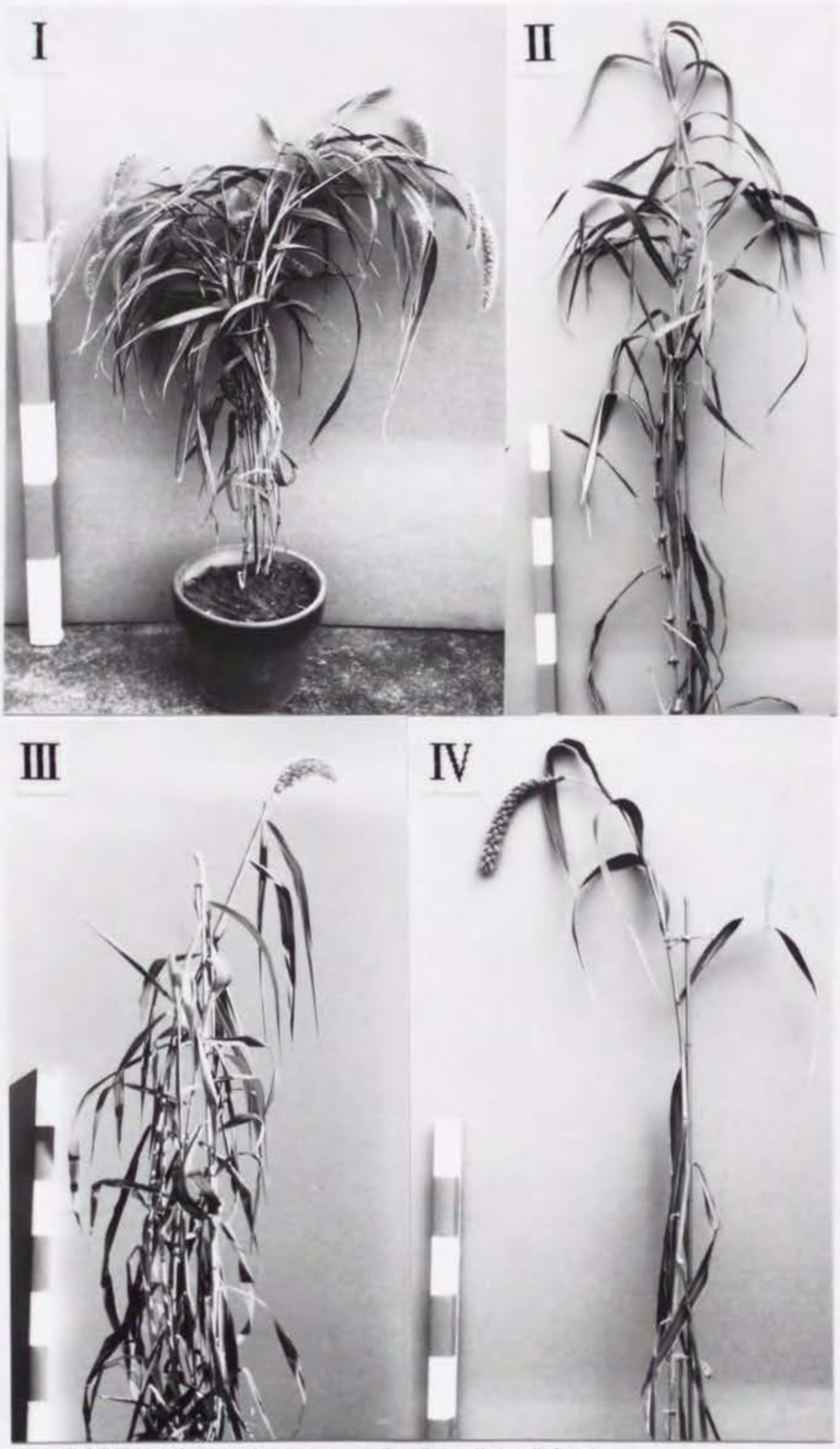

Fig. 6. Four tillering types of *S. italica*.
Type I: the Chitral group of northern Pakistan, Type II: the strain from India, Type III: the strain from Japan, Type IV: the strain from Kochi Prefecture, Japan.

Type II. Type II plants eventually produced two or three effective tillers. The strains from India (85-11-10-1-2), Nepal (75-10-9-1), Thailand (75-2-12-2) and Taiwan (72-8-8) were recognized as Type II.

As shown in Figs. 5 and 6, the Type III strains had a non-tillering habit that produced only one panicle at the top of the main culm. The Baltistan group of northern Pakistan (87-10-2-2-1) and the strains from Georgia (74-9-21-7), India (K87-10-11-6-3), Nepal (75-10-7-3), Indonesia (81-6-10-1), China (81-2-6-1), Korea (77-12-12-4) and Japan (72-10-7-4) were Type III. When the development of the main culm of Type III was halted by disease or insect injury, many abnormal tillers started to grow irregularly from the upper nodes of the main culm.

The Types II and III strains used in the present study showed wide variation in earliness and the number of nodes on the main culm, including early heading strains with a small number of nodes and also late heading ones with a large number of nodes. The late heading Type II strains bore many leaves on the primary tillers.

One strain from Kochi Prefecture, Japan (72-10-8-8) showed an exceptional pattern of tiller development as shown in Figs. 5 and 6, and was classified as Type IV. Type IV had characteristics intermediate between Types I and II. Production of many primary tillers and the presence of secondary tillers were the traits shared by Types IV and I. On the other hand, the primary tillers of Type IV were found only at lower nodes on the main culm, as was seen in the Type II plants. The Type IV strain was late heading and bore a large number of leaves both on the main culm and on the primary and secondary tillers.

After defining the four tillering types as above, the Chitral group of northern Pakistan was classified as Type I. Most strains of the Baltistan group were Type III, with the three exceptions of Type II (87-10-8-4-1, 87-10-8-4-2 and 87-10-9-4-3). The Dir group was comprised of five Type I strains and one Type III strain (87-9-21-1-1). The 70 strains from Eurasia observed in chapter 2 were grouped as follows; 34 strains were Type I, 11 were Type II, 24 were Type III and one was Type IV. Table 12 shows the geographical distribution of the four tillering types in 70 strains from Eurasia, three strains of the Chitral group and three strains of the Baltistan group. The strains of the western regions of Eurasia, from Europe, Central Asia to Southwest Asia, were abundant in Type I. Also, Type I included the strains from South Asia, namely the Chitral group of northern Pakistan, four strains from southern Pakistan, four strains from India, one from Nepal and one from Bangladesh. This type was rarely found in eastern regions of Eurasia from Southeast Asia to East Asia. Only four east Eurasian strains each from Indonesia, Taiwan, China and Japan were Type I. The strains of Types II and III were mainly distributed from South Asia to East Asia. Type III was frequently observed among the East Asian

Table 12. Geographical distribution of four tillering types of *S. italica* in Eurasia

Area	Number of strains	Type I No.(%)	Type II No.(%)	Type III No.(%)	Type IV No.(%)
Europe	9	9(100.0)	0	0	0
Central and Southwest Asia	12	11(91.7)	0	1(8.3)	0
South Asia*	30	13(43.3)	5(16.7)	12(40.0)	0
Southeast Asia	7	1(14.3)	4(57.1)	2(28.6)	0
East Asia	18	3(16.7)	2(11.1)	12(66.7)	1(5.6)
Total	76	37(48.7)	11(14.5)	27(35.5)	1(1.3)

*: The South Asian strains contained three strains of the Chitral group and three ones of the Baltistan group from northern Pakistan.

strains. Types II and III strains could not be found in Europe and Central and Southwest Asia, with the exception of one Type III strain from Georgia. Among the 76 strains examined, only one strain from Kochi Prefecture, Japan was Type IV.

Genetic analysis of tillering types

Tillering characters of F_1 hybrids and their parental strains are summarized in Table 13.

All the F_1 hybrids (95109, 95110 and 95115), obtained by crosses between the Type I strains and the strains of Types II, III and IV, produced a large number of primary tillers that widely located on the main culm, and also secondary and tertiary tillers and tillers of prophyll. The tillering pattern of these F_1 hybrids was regarded as Type I. This result indicates that the tillering pattern of Type I was dominant over all the other tillering types.

The F_1 hybrid (95116) between the strains of Types IV and III had three primary tillers that developed at the lower nodes on the main culm, as observed in the Type IV strain. It could be concluded that the tillering pattern of Type IV was dominant over that of Type III.

Table 13. Tillering characters in F_1 hybrids and their parental strains of *S. italica*

	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers: Lowest	Position of nodes with primary tillers: Highest	Number of effective tillers: Primary	Number of effective tillers: 2nd & 3rd	Number of effective tillers: Pro-phyll	Number of effective tillers: Total
Parental strains								
Type I								
95101	56.4[1]	13.8	4.0	12.6	7.8	27.2	2.7	38.4
(n=5)	0.80[2]	0.75	0.0	0.49	1.17	7.17	1.36	9.09
	56 - 58[3]	13 - 14	—	12 - 13	6 - 9	16 - 35	1 - 4	24 - 49
95102 (n=2)	51.0	13.5	3.5	10.0	3.5	4.5	0.0	9.0
Type II								
95104	64.0	17.8	—	—	0.0	—	—	1.0
(n=4)	0.0	0.4	—	—	0.0	—	—	0.0
	—	17 - 18	—	—	—	—	—	—
Type III								
93106	87.8	20.4	—	—	0.0	—	—	1.0
(n=5)	0.98	0.80	—	—	0.0	—	—	0.0
	87 - 89	19 - 21	—	—	—	—	—	—
Type IV								
95107 (n=2)	125.0	25.0	3.0	8.5	6.0	1.5	0.0	9.0
F_1 hybrids								
95101x95102								
95108	51	13	4	11	8	19	4	32
95101x95104								
95109	56	15	5	14	9	12	5	37
95101x95106								
95110	64	16	3	15	10	43	2	56
95107x95102								
95115	53	15	6	13	7	15	3	26
95107x95106								
95116	110	23	4	6	3	0	0	4

n: number of plants observed, 1)mean, 2)SD, 3)range.

DISCUSSION

In the present chapter, four tillering types of *S. italica*, Types I - IV, were identified. The types differed in the total number of effective tillers, and in the pattern of tiller development. Based on the observation of tiller development and genetic analysis, the four tillering types appear to be genetically determined with little environmental influence.

Type I was characterized by a large number of tillers including primary, secondary and tertiary tillers and also tillers of prophyll, and was judged as the dominant phenotype. *S. viridis*, the probable ancestor of *S. italica*, also produced a large number of tillers. On the other hand, the tillering patterns of Types II and III that bore a small number of tillers were clearly distinct from Type I. It was assumed that Types II and III were genetically controlled to display strong apical dominance at all growth stages by recessive gene(s). The abnormal tillers observed at the upper nodes of the main culm of Type III could have developed accidentally due to the disappearance of strong apical dominance after the formation of a young panicle.

The Types II and III strains bore large panicles with developed rachis branches. This had an effect on agricultural practices and utilization methods of *S. italica* in Southeast and East Asia. *S. italica* with a few tillers was harvested by cutting just below the panicle in the

Nansei Islands (Takei 1989) and the Kii mountains, Japan (Takei *et al.* 1981). Takei (1994) reported many kinds of tools specific to removing the *S. italica* panicle which were used in the Nansei Islands and other areas of Japan. Whole panicles were stored without threshing for the next sowing in northern Thailand (Ochiai 1995) and used for ceremony and rituals in Taiwan (Mabuchi 1988). Farmers in Ishikawa Prefecture, Japan distinguished several local varieties of *S. italica* by the morphological traits of their panicles (Tachibana 1995).

Type IV was found in only one strain collected at Kochi Prefecture, Japan. No other strains from Eurasia could be classified as Type IV. This strain is the highly endemic landrace locally known as "*Shimokatsugi* (frost carrier)" and has waxy-endosperm grains (Sakamoto 1995). This late heading landrace is restricted to the central and eastern mountains of Shikoku Island, and could not be found in any other areas of Japan. *Shimokatsugi* is presumably well-adapted to the traditional system of shifting cultivation on this island. The tillering pattern of Type IV appeared dominant over that of Type III. This indicates that the unusual tillering character of Type IV was not derived from a recessive mutation which occurred in a limited area of Shikoku Island.

Types I, II and III strains are not evenly distributed across Eurasia. Almost all the strains from Europe and Central and Southwest Asia were Type I, except for one Type

III strain from Georgia. A great diversity of *S. italica* in Georgia was reported by Dekaprelevich and Kasparian (1928). They suggested that non-tillering strains originated in Georgia independent of other areas. In eastern Eurasia from Southeast Asia to East Asia, the strains of Types II and III were frequent, and those of Type I were rare. In South Asia including northern Pakistan, a high diversity of tillering types was observed, namely, strains of Types I, II and III were all present.

Chapter 4: Characteristics of *Setaria* weeds collected at two villages in northern Pakistan

INTRODUCTION

The distribution areas of *S. italica* frequently overlap with those of *S. viridis*, and natural hybridization between them has been reported. Darmency et al. (1987) estimated that the outcrossing rate between the two species is 0.4 to 2.8%. Progeny of hybrids between them showed regular chromosome pairing and normal fertility (Kihara and Kishimoto 1942). In contrast to the above, crosses between *S. italica* and *S. verticillata*, the latter of which is a tetraploid (2n=36) weed of *S. italica* fields in France, produced a sterile triploid (2n=27) (Poirier-Hamon and Pernes 1986, Sakamoto 1988). Also, associated *Setaria* weed forms have been observed in several cultivation areas of *S. italica* (Tsvelev 1976, Kobayashi 1988, Ochiai 1996a).

In northern Pakistan, *S. viridis* was commonly found on roadsides and at the edge and inside of *S. italica* fields. In addition to *S. italica* and *S. viridis*, unidentified *Setaria* plants were also collected (Kawase and Sakamoto 1989). These included mimetic weed-like plants, associated weed forms (giant foxtail type) and hybrid-like plants between *S. italica* and *S. viridis*. In this chapter, characteristics of *Setaria* samples including those from the

Chitral and Baltistan groups, *S. viridis* and unidentified *Setaria* plants that were originally collected at two villages in northern Pakistan were observed and compared each other.

MATERIALS AND METHODS

Plant materials used in the present chapter were collected at two villages in northern Pakistan: Bambreet village in the Chitral District, N.W.F.P., and Goon village in Baltistan.

A *S. italica* sample (87-9-24-2-2) identified in chapter 2 as a member of the Chitral group and two samples of *Setaria* (87-9-24-2-3 and 87-9-24-2-4) collected in the same field in Bambreet village were used as shown in the upper part of Table 14. Panicles in the collection bag of 87-9-24-2-3 and 87-9-24-2-4 were divided into six cultivation lines (B1 family, cultivation No.93002 to 93007) and eight cultivation lines (B2 family, cultivation No.93008 to 93015) respectively, at the time of sowing.

Of Goon village samples, three *S. italica* samples (87-10-8-4-1, 87-10-8-4-4 and 87-10-8-4-5) which belonged to the Baltistan group and four samples of *Setaria* (87-10-8-4-3, 87-10-8-4-6, 87-10-8-4-7 and 87-10-8-4-8) were used for the experiment as shown in the middle part of Table 14. One *Setaria* sample (87-10-8-4-3) was collected in one field (87-

Table 14. *Setaria* samples from two villages in northern Pakistan

Cultivation number	Collection number	Field observation and identification*
Bambreet village, Chitral District, N.W.F.P.		
93001	87-9-24-2-2	*Setaria italica*
B1 family		
93002	87-9-24-2-3-a	*S. viridis*?
93003	-b	(mimic to *S. italica*)
93004	-c	
93005	-d	
93006	-e	
93007	-f	
B2 family		
93008	87-9-24-2-4-a	*S. viridis*
93009	-b	
93010	-c	
93011	-d	
93012	-e	
93013	-f	
93014	-g	
93015	-h	
Goon village, Baltistan		
93016	87-10-8-4-1	*S. italica*
93018	87-10-8-4-3	*Setaria* sp. (a natural hybrid?)
93019	87-10-8-4-4	*S. italica*
93020	87-10-8-4-5	*S. italica*
G2 family		
93021	87-10-8-4-6-a	*Setaria* sp. (a natural hybrid?)
93022	-b	
93023	-c	
93024	-d	
93025	87-10-8-4-7	*Setaria* sp. (*S. italica*-like)
93026	87-10-8-4-8	*Setaria viridis*? (a giant foxtail type)
Shangla Top, N.W.F.P.		
93036	87-9-18-5-2-a	*S. viridis*
93037	-b	
Jotal, Hunza Valley, Gilgit Agency		
93038	87-10-2-1-3-a	*S. viridis*
93039	-b	

*: Kawase and Sakamoto (1989).

10-8-4-1), while three other samples (87-10-8-4-6, 87-10-8-4-7 and 87-10-8-4-8) were collected in another field (87-10-8-4-4 and 87-10-8-4-5). Panicles of 87-10-8-4-6 were divided into four cultivation lines (G2 family, cultivation No.93021 to 93024).

Additionally, two *S. viridis* samples shown in the lower part of Table 14 were used for comparison with other *Setaria* samples. One (87-9-18-5-2) was collected along the roadside at Shangla Top, N.W.F.P., and the other (87-10-2-1-3) was found in *Vigna radiata* field in Jotal, Gilgit Agency. These collection sites were located far away from Bambreet and Goon villages, and other *S. italica* fields. Two panicles of each sample were divided into two cultivation lines for the experiment (cultivation No.93036 and 93037; and 93038 and 93039, respectively).

All the plant materials were sown on May 17, 1993 in wooden nursery boxes filled with sterilized soil. One month later, 10 seedlings per sample for *S. italica* and *S. viridis*, and 15 to 30 seedlings per sample for other *Setaria* samples were transplanted to cultivation beds in glasshouses in Kyoto, Japan at 35°N latitude. They were grown without temperature or daylength control.

The following characters at each growth stage were observed.

1). Seedling characters: germination rate; germination energy for three days; anthocyan pigmentation on seedlings; length of the cotyledon and first and second leaves.

2). Characters at the vegetative stage: number of days to heading; number of leaves on the main culm; plant height; pubescence of leaf sheath: highly pubescent, pubescent or glabrous.

3). Tillering characters: position of nodes with primary tillers; number of primary effective tillers; number of secondary and tertiary effective tillers and effective tillers of prophyll; total number of tillers including the main culm.

4). Panicle characters: panicle length; panicle type: short-conical, conical, cylindrical or long-conical; anther color: brown, orange or white; bristleness: very long, long, medium or short; anthocyan pigmentation on bristle; pubescence of rachis: pubescent or glabrous; shattering habit: non-shattering, semi-shattering or shattering.

5). Grain characters: color of lemma and palea: yellow, green yellow or brown; color of fruits: yellow or gray; grain length (L) and width (W) and their product (LxW) and ratio (L/W); thousand grain weight; phenol color reaction of fruits.

RESULTS

Characters of the *Setaria* samples from Bambreet and Goon villages and those of the *S. viridis* samples from Shangla Top and Jotal are summarized in the upper, middle and lower parts of Tables 15, 16, 17 and 18, respectively.

Characteristics of the *Setaria* samples from Bambreet village

The three Bambreet village samples, 93001 and the B1 and B2 families, had common characters as follows: early heading (Fig. 7), short plant height (Fig. 8) and short-conical panicles with short primary rachis branches without secondary branches (Fig. 9). Based on the tillering characters shown in Table 19, the tillering pattern of 93001 and the B1 and B2 families could be classified as the Type I previously observed in chapter 3. The samples had many primary tillers (4.6 to 8.0) spread widely on the nodes of the main culm, and also had secondary and tertiary tillers and tillers of prophyll. Also, the tillering pattern of the *S. viridis* samples from Shangla Top and Jotal could be regarded as Type I, according to the tillering characters shown in Table 20.

However, the B1 and B2 families were distinguished from 93001 by the following characters at seedling stage: high germination rate, high germination energy and long seedling leaves. The B1 and B2 families, however, showed low germination rate (26.0 to 79.4%), low germination energy

Table 15. Seedling characters of *Setaria* samples

Cult. number	Germination rate (%)	Germination energy (%)	Seedling color*	Leaf length (cm) Cotyledon Mean	Cotyledon SD	First leaf Mean	First leaf SD	Second leaf Mean	Second leaf SD
Bambreet village									
93001	88.0	86.0	G	1.48	0.121	3.34	0.361	5.20	0.851
B1 family									
93002	76.7	53.3	G	1.34	0.103	2.46	0.251	4.26	0.535
93003	52.0	24.0	G	1.30	0.090	2.20	0.199	4.06	0.811
93004	56.0	44.0	G	1.24	0.103	2.24	0.349	4.38	0.614
93005	44.0	22.0	G	1.08	0.074	1.80	0.260	3.50	0.556
93006	64.0	36.0	G	1.14	0.164	1.90	0.423	3.60	0.228
93007	62.0	30.0	G	1.16	0.137	1.98	0.159	3.96	0.224
B2 family									
93008	76.0	74.0	R	0.94	0.049	1.86	0.137	3.26	0.338
93009	40.0	28.0	R	0.84	0.049	1.58	0.204	2.44	0.403
93010	63.6	45.5	R	0.96	0.137	1.96	0.164	3.02	0.520
93011	62.5	54.2	R	1.06	0.166	2.14	0.390	4.29	0.491
93012	53.3	35.5	R	1.02	0.074	1.92	0.318	3.22	0.307
93013	42.3	34.6	R	0.80	0.063	1.60	0.228	2.44	0.361
93014	79.4	67.6	R	1.10	0.083	2.01	0.260	3.35	0.417
93015	26.0	16.0	R	0.87	0.060	1.40	0.423	2.13	0.267
Goon village									
93016	88.0	88.0	R	1.30	0.110	2.46	0.195	4.24	0.542
93018	98.3	96.7	G/R	1.39	0.128	3.08	0.276	5.70	0.464
93019	96.0	76.0	G	1.50	0.211	2.76	0.186	5.04	0.412
93020	92.0	92.0	G	1.40	0.134	2.98	0.213	5.20	0.715
G2 family									
93021	98.3	93.3	G	1.16	0.085	2.29	0.128	4.41	0.323
93022	68.0	38.0	G	1.14	0.092	2.27	0.242	3.80	0.414
93023	86.0	86.0	G	0.96	0.112	1.80	0.255	3.66	0.372
93024	70.0	62.0	G	1.18	0.087	1.99	0.309	3.22	0.457
93025	91.7	90.0	G	1.18	0.090	2.29	0.184	3.60	0.405
93026	49.1	25.5	G	1.46	0.148	2.60	0.220	4.83	0.858
Shangla Top									
93036	21.9	15.6	R	0.64	0.103	1.02	0.159	1.85	0.280
93037	63.3	53.3	R	0.76	0.137	1.44	0.103	2.10	0.332
Jotal									
93038	67.5	65.0	R	0.95	0.087	1.83	0.164	3.65	0.383
93039	81.3	81.3	R	0.91	0.074	1.60	0.235	2.85	0.426

*: R and G indicates seedling with and without anthocyan pigmentation, respectively.

Table 16. Characters at the vegetative stage of *Setaria* samples

Cult. number	No. days to heading		Number of leaves		Plant height (cm)		Pubescence of leaf sheath*
	Mean	SD	Mean	SD	Mean	SD	
Bambreet village							
93001	47.2	1.03	9.1	0.30	70.3	4.97	G
B1 family							
93002	60.7	7.50	11.7	2.37	105.6	19.13	HP
93003	65.0	6.26	12.4	2.04	118.2	21.43	HP
93004	57.3	7.96	10.3	1.49	101.3	15.93	HP
93005	66.2	8.09	12.0	1.48	97.7	15.93	HP
93006	64.1	5.70	12.3	1.47	122.6	14.83	HP
93007	66.1	5.69	12.6	1.37	133.9	16.94	HP
B2 family							
93008	55.8	4.29	10.7	0.99	94.1	12.24	G
93009	56.4	4.13	10.8	0.92	81.8	9.00	G
93010	49.6	4.84	9.0	0.67	71.8	8.83	G
93011	47.0	3.48	8.1	0.78	65.0	13.18	G
93012	42.9	4.29	8.1	0.68	62.2	12.45	G
93013	46.8	7.39	9.3	1.06	70.1	14.20	G
93014	56.8	4.65	10.5	1.02	81.4	12.33	G
93015	60.9	8.69	11.6	1.72	89.5	15.23	G
Goon village							
93016	56.9	1.25	12.6	0.74	118.5	15.22	G
93018	53.9	14.77	11.1	3.43	118.9	60.91	G
93019	55.6	2.50	13.2	1.47	112.8	18.08	G
93020	48.2	0.42	10.2	0.79	88.5	7.00	G
G2 family							
93021	57.4	3.60	14.0	1.92	140.7	30.62	G
93022	57.4	2.36	13.4	1.50	139.4	21.22	G
93023	54.2	2.70	12.7	1.54	119.5	14.83	G
93024	57.3	2.72	15.5	1.66	108.5	35.09	G
93025	54.0	2.81	13.4	1.50	137.1	23.47	G
93026	75.0	4.58	14.3	2.08	156.7	36.89	P
Shangla Top							
93036	45.3	5.50	11.0	1.26	59.1	7.52	G
93037	43.4	3.06	10.9	0.59	55.4	6.58	G
Jotal							
93038	59.2	1.91	13.7	0.69	94.8	11.48	G
93039	62.0	5.55	13.4	0.74	112.1	21.96	G

*: HP, P and G indicate highly pubescent, pubescent and glabrous, respectively.

Table 17. Panicle characters of *Setaria* samples

Cult. number	Panicle length(cm) Mean	SD	Pani-cle type	Anth-er color	Bristle-ness	Bristle color	Pubes-cence of rachis	Shatter-ing habit
Bambreet village								
93001	9.7	0.66	SC[1)]	O[2)]	L[3)]	G[4)]	G[5)]	NS[6)]
B1 family								
93002	12.1	2.70	SC	B	VL	G	P	S
93003	13.3	1.66	SC	B	VL	G	P	S
93004	12.0	1.63	SC	B	VL	G	P	S
93005	12.2	2.05	SC	B	VL	G	P	S
93006	13.7	1.25	SC	B	VL	G	P	S
93007	14.9	1.93	SC	B	VL	G	P	S
B2 family								
93008	10.5	1.39	SC	B	VL	G	G	S
93009	12.0	1.28	SC	B	VL	G	G	S
93010	9.9	1.20	SC	B	VL	G	G	S
93011	8.9	2.16	SC	B	VL	G	G	S
93012	8.3	1.93	SC	B	VL	G	G	S
93013	9.1	1.86	SC	B	VL	G	G	S
93014	13.0	1.50	SC	B	VL	G	G	S
93015	11.9	1.02	SC	B	VL	G	G	S
Goon village								
93006	12.4	2.60	CO	W	S	R	G	NS
93018	17.5	12.57	SC /CO /CL	B /W	S /L	G /R	G	NS /SE /S
93019	14.8	2.06	CO	W	S	G	G	NS
93020	11.1	1.23	CL	W	S	G	G	NS
G2 family								
93021	17.9	4.26	CO	W	S	G	G	S /SE
93022	19.1	3.80	CO	W	S	G	G	S
93023	16.0	3.15	CO	W	S	G	G	S
93024	13.2	3.22	CO	W	S	G	G	S
93025	11.6	3.59	CO /CL	W	S	G /R	G	NS /SE /S
93026	20.5	4.22	LC	W	L	G	P	S
Shangla Top								
93036	5.6	0.24	SC	B	VL	G	G	S
93037	5.5	1.06	SC	B	VL	G	G	S
Jotal								
93038	7.8	0.93	SC	B	VL	G	G	S
93039	9.0	1.08	SC	B	VL	G	G	S

1)SC, CO, CL and LC indicates short-conical, conical, cylindrical and long-conical panicles, respectively.
2)O, B and W indicate orange, brown and white colored anthers, respectively.
3)VL, L and indicate very long, long and short bristle, respectively.
4)R and G indicate bristle with and without anthocyan pigmentation, respectively.
5)P and G indicate pubescence and glabrous of rachis, respectively.
6)NS, SE and S indicate non-shattering, semi-shattering and shattering habits, respectively.

Table 18. Grain characters of *Setaria* samples

Cult. number	Length(L) (mm)		Width(W) (mm)		LxW		L/W	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bambreet village								
93001	2.61	0.076	1.76	0.054	4.60	0.217	1.48	0.056
B1 family								
93002	2.28	0.010	1.39	0.068	3.16	0.220	1.64	0.101
93003	2.31	0.099	1.38	0.054	3.25	0.297	1.67	0.115
93004	2.32	0.077	1.29	0.061	2.99	0.175	1.80	0.106
93005	2.25	0.076	1.39	0.065	3.06	0.201	1.62	0.104
93006	2.30	0.059	1.39	0.054	3.19	0.119	1.66	0.089
93007	2.23	0.095	1.38	0.051	3.07	0.138	1.62	0.102
B2 family								
93008	1.99	0.244	1.22	0.044	2.49	0.113	1.83	0.246
93009	2.03	0.044	1.19	0.041	2.41	0.076	1.84	0.657
93010	2.03	0.097	1.68	0.084	2.45	0.172	1.68	0.084
93011	2.16	0.077	1.20	0.028	2.59	0.095	1.80	0.084
93012	2.10	0.077	1.23	0.068	2.59	0.218	1.70	0.088
93013	2.13	0.056	1.24	0.063	2.64	0.138	1.72	0.100
93014	2.08	0.066	1.31	0.063	2.72	0.134	1.60	0.104
93015	1.93	0.058	1.23	0.043	2.38	0.093	1.57	0.084
Goon village								
93016	2.20	0.096	1.95	0.068	4.30	0.193	1.13	0.072
93018	2.25	0.060	1.69	0.096	3.79	0.232	1.33	0.085
93019	2.52	0.096	2.10	0.085	5.30	0.270	1.20	0.070
93020	2.37	0.069	1.96	0.092	4.64	0.235	1.22	0.073
G2 family								
93021	2.37	0.047	1.77	0.046	4.19	0.010	1.34	0.056
93022	2.39	0.136	1.62	0.016	3.79	0.090	1.45	0.035
93023	2.29	0.051	1.72	0.049	3.93	0.040	1.33	0.065
93024	2.38	0.046	1.59	0.050	3.80	0.161	1.49	0.040
93025	2.48	0.066	1.95	0.048	5.06	0.813	1.28	0.047
93026	2.21	0.096	1.38	0.085	3.08	0.317	1.61	0.062
Shangla Top								
93036	2.02	0.110	1.09	0.051	2.20	0.177	1.85	0.109
93037	2.00	0.092	1.13	0.161	2.18	0.155	1.82	0.100
Jotal								
93038	1.99	0.104	1.11	0.081	2.21	0.200	1.79	0.158
93039	2.40	0.175	1.18	0.078	2.40	0.175	1.74	0.155

Continued

Table 18. Grain characters of *Setaria* samples

Cult. number	Color of lemma & palea	Color of fruits	1000 grain weight (g) Mean	SD	Phenol color reaction
Bambreet village					
93001	Y[1)]	Y[2)]	2.54	0.208	-
B1 family					
93002	GY	Y	1.49	0.050	+
93003	GY	Y	1.53	0.075	+
93004	GY	Y	1.52	0.043	+
93005	GY	Y	1.48	0.080	+
93006	GY	Y	1.53	0.025	+
93007	GY	Y	1.47	0.052	+
B2 family					
93008	GY	Y	1.03	0.034	+
93009	B	G	0.99	0.005	+
93010	B	G	1.03	0.019	+
93011	B	G	1.12	0.049	+
93012	B	G	1.03	0.094	+
93013	GY	Y	1.03	0.050	+/-
93014	B	Y	1.13	0.009	+
93015	B	Y	1.01	0.034	+
Goon village					
93016	Y	Y	3.01	0.041	-
93018	Y/B	Y/G	2.34	0.242	+/-
93019	Y	Y	3.55	0.025	-
93020	Y	Y	2.80	0.102	-
G2 family					
93021	Y/B	Y	2.48	0.151	+
93022	B	Y	2.02	0.043	+
93023	B	Y	2.03	0.025	+
93024	B	Y	1.77	0.347	+
93025	B	Y	2.81	0.109	+/-
93026	B	G	1.68	0.326	+
Shangla Top					
93036	B	G	0.77	-	+
93037	B	G	0.87	0.019	+
Jotal					
93038	B	G	0.92	0.016	+
93039	B	G	0.98	0.057	+

1)Y, GY and B indicate yellow, green yellow and brown colored lemma and palea, respectively.

2)Y and G indicate yellow and green colored fruits, respectively.

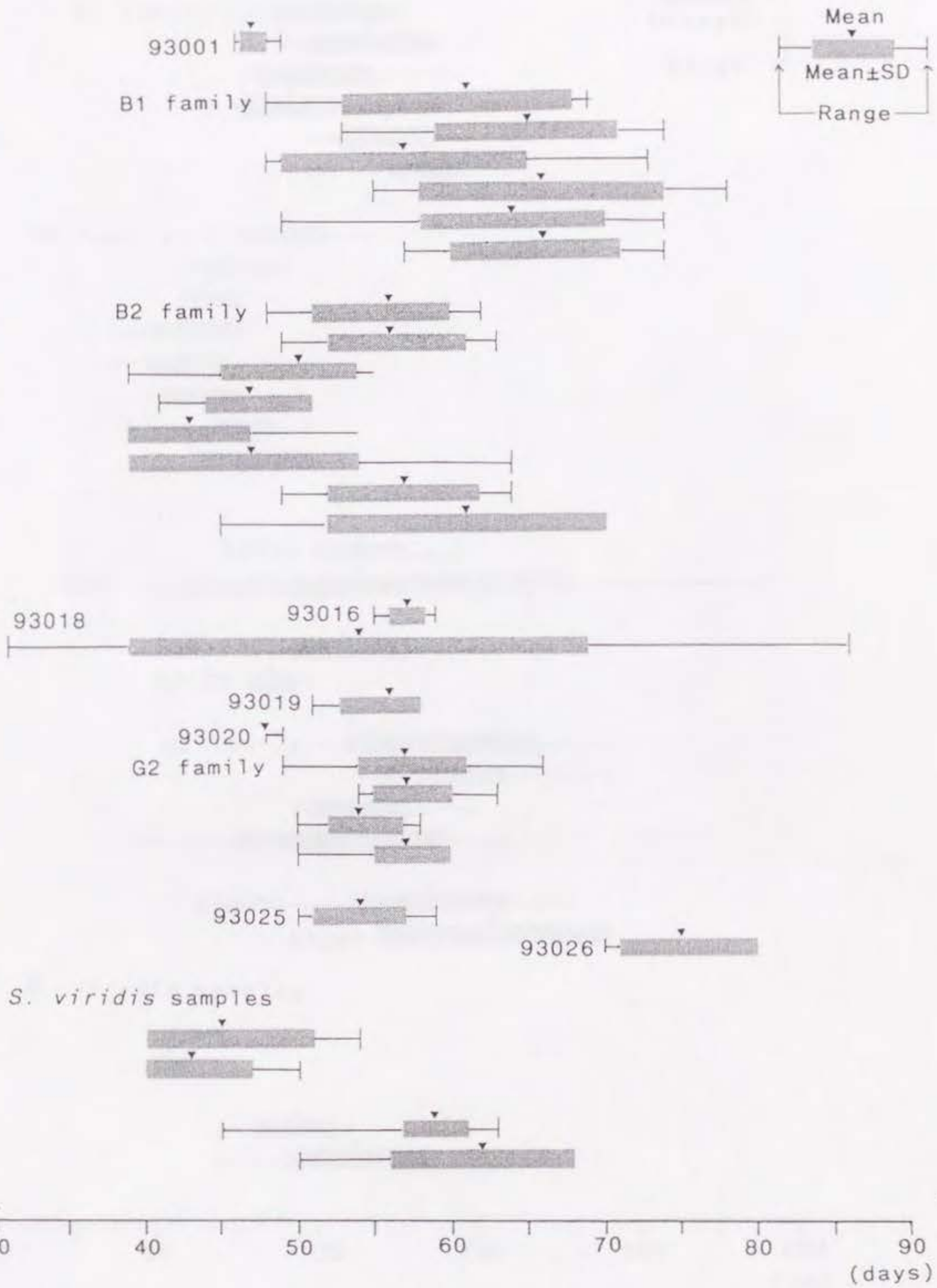

Fig. 7. Variability in number of days to heading of *Setaria* samples.

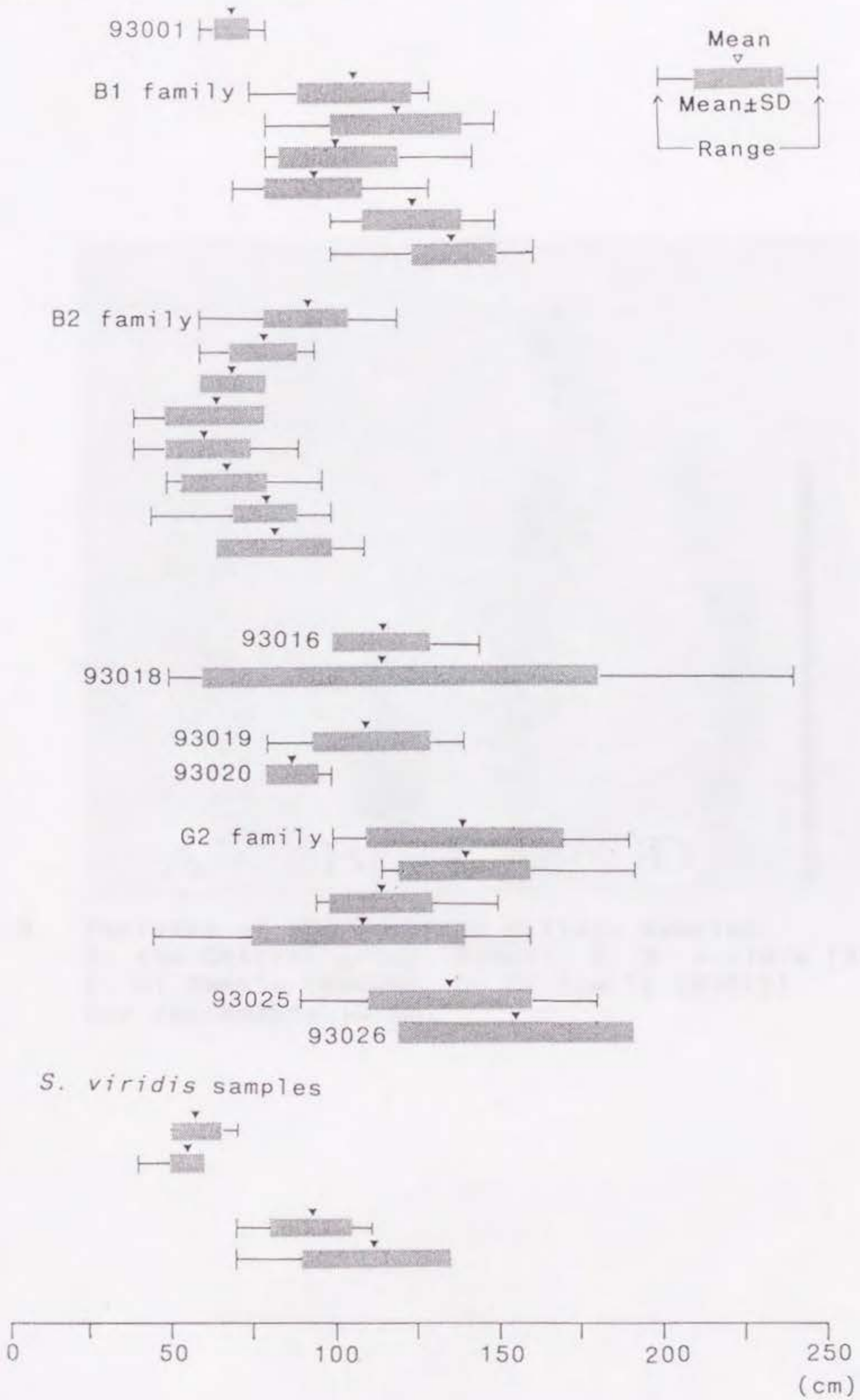

Fig. 8. Variability in plant height of *Setaria* samples.

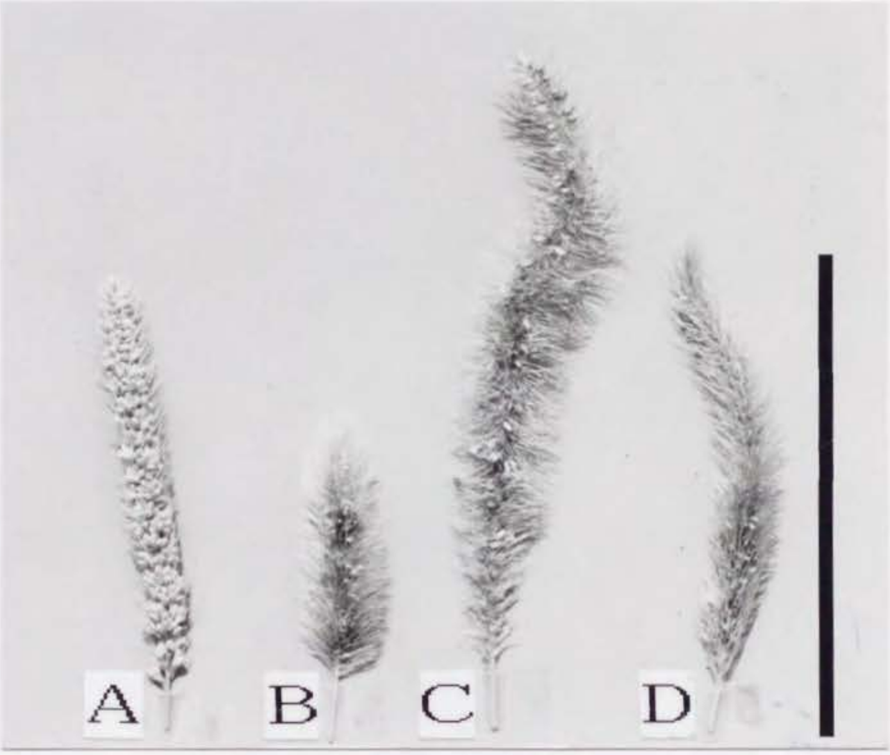

Fig. 9. Panicles of the Bambreet village samples.
A: the Chitral group (93001), B: *S. viridis* (93039), C: G1 family (93006), D: G2 family (93013).
Bar represents 10 cm.

Table 19. Tillering characters of the Bambreet village samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers		Number of effective tillers		
			Lowest	Highest	Primary	2nd, 3rd & prophyll	Total
S. italica							
93001	47.2[1)]	9.1	2.8	6.3	4.6	2.6	7.0
(n=9)	1.03[2)]	0.30	0.63	0.67	0.96	1.50	1.76
	46 - 49[3)]	9 - 10	2 - 4	5 - 7	3 - 6	1 - 6	5 - 10
B1 family							
93002	60.7	11.7	2.9	8.1	5.5	15.0	21.5
(n=15)	7.50	2.37	0.34	2.06	1.54	12.49	13.40
	48 - 69	8 - 15	2 - 3	5 - 12	3 - 9	2 - 42	7 - 52
93003	65.0	12.4	3.0	8.7	5.3	10.1	15.6
(n=19)	6.26	2.04	0.32	0.95	1.45	5.78	7.25
	53 - 74	9 - 15	2 - 4	4 - 11	3 - 9	2 - 21	6 - 28
93004	57.3	10.3	3.0	7.3	4.9	9.9	13.8
(n=13)	7.96	1.49	0.39	1.26	1.00	5.70	5.15
	48 - 73	9 - 13	2 - 4	4 - 10	2 - 6	2 - 24	9 - 30
93005	66.2	12.0	2.7	7.8	5.3	3.3	9.6
(n=11)	8.09	1.48	0.62	1.70	1.05	1.96	2.42
	55 - 78	10 - 14	2 - 4	6 - 11	4 - 8	0 - 6	5 - 13
93006	64.1	12.3	2.8	8.0	5.1	11.2	17.3
(n=22)	5.70	1.47	0.42	1.85	1.35	8.31	9.28
	57 - 74	10 - 15	2 - 3	5 - 11	3 - 8	1 - 37	5 - 46
93007	66.1	12.6	3.0	7.8	4.6	10.4	16.0
(n=23)	5.69	1.37	0.52	2.19	1.58	8.67	9.52
	53 - 73	10 - 15	2 - 4	5 - 11	2 - 9	0 - 41	6 - 47

Continued

n: number of plants observed, 1)mean, 2)SD, 3)range.

Table 19. Tillering characters of the Bambreet village samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers: Lowest	Position of nodes with primary tillers: Highest	Number of effective tillers: Primary	Number of effective tillers: 2nd, 3rd & prophyll	Number of effective tillers: Total
B2 family							
93008	55.8[1)]	10.7	1.70	8.4	7.7	24.3	33.4
(n=27)	4.29[2)]	0.99	1.08	0.99	1.20	20.37	20.96
	48 - 63[3)]	9 - 13	1 - 4	7 - 10	5 - 10	0 - 87	6 - 98
93009	56.4	10.8	1.7	9.0	8.2	17.5	28.2
(n=15)	4.13	0.92	0.87	0.82	1.11	9.51	9.33
	49 - 63	10 - 13	1 - 3	8 - 11	6 - 10	7 - 37	14 - 48
93010	49.6	9.0	2.6	7.6	6.0	14.0	21.0
(n=8)	4.84	0.67	1.11	0.70	1.41	11.49	12.14
	39 - 55	8 - 10	1 - 4	7 - 9	4 - 8	3 - 43	8 - 51
93011	47.0	8.1	3.4	6.9	4.6	17.3	22.8
(n=19)	3.48	0.78	0.88	0.71	1.46	15.13	15.71
	42 - 51	7 - 10	1 - 4	6 - 8	3 - 8	2 - 43	7 - 49
93012	42.9	8.1	3.1	6.9	4.8	11.5	17.3
(n=16)	4.29	0.68	0.56	0.70	0.66	5.47	5.67
	39 - 54	7 - 9	2 - 4	6 - 8	4 - 6	2 - 20	7 - 25
93013	46.8	9.3	1.8	7.8	7.0	23.1	31.1
(n=8)	7.39	1.06	0.97	1.10	1.50	17.10	17.42
	39 - 64	8 - 12	1 - 3	6 - 10	5 - 10	5 - 55	11 - 64
93014	56.8	10.5	1.3	8.4	8.0	19.7	28.7
(n=15)	4.65	1.02	0.60	1.00	0.97	9.86	10.24
	49 - 64	9 - 13	1 - 3	7 - 11	6 - 10	6 - 35	15 - 44
93015	60.9	11.6	2.2	8.8	7.4	25.8	32.6
(n=5)	8.69	1.72	0.75	1.33	1.36	16.44	17.74
	45 - 67	9 - 13	1 - 3	7 - 11	5 - 9	14 - 68	22 - 68

n: number of plants observed, 1)mean, 2)SD, 3)range.

Table 20. Tillering characters of the *S. viridis* samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers		Number of effective tillers		
			Lowest	Highest	Primary	2nd, 3rd & prophyll	Total
Shangla Top							
93036	45.5[1)]	11.0	1.0	8.8	8.8	128.3	138.0
(n=4)	5.50[2)]	1.26	0.0	0.43	0.43	81.36	81.71
	40 - 54[3)]	10 - 13	——	8 - 9	8 - 9	12 - 244	23 - 254
93037	43.4	10.9	1.1	8.8	8.6	73.5	88.7
(n=10)	3.06	0.59	0.87	1.08	0.80	67.35	64.33
	40 - 50	10 - 12	0 - 2	8 - 11	7 - 10	22 - 213	36 - 223
Jotal							
93038	59.2	13.7	1.1	9.8	9.2	24.2	34.6
(n=18)	1.91	0.69	0.57	1.58	1.21	12.55	12.93
	55 - 63	12 - 15	0 - 2	8 - 12	7 - 11	5 - 54	14 - 66
93039	62.0	13.4	1.4	11.4	10.9	26.6	38.4
(n=7)	5.55	0.74	0.90	1.05	0.64	25.44	25.85
	50 - 67	12 - 14	0 - 3	9 - 12	10 - 12	3 - 72	14 - 84

n: number of plants observed, 1)mean, 2)SD, 3)range.

(16.0 to 67.6%) and short seedling leaves. Wide variability in number of days to heading was observed in the B1 and B2 families, in comparison with 93001. The panicle of 93001 was characterized by orange colored anthers, long bristles and a non-shattering habit. On the other hand, brown colored anthers, very long bristles and a shattering habit were observed in the B1 and B2 families. Grains of the B1 and B2 families were small, oblong and light, in contrast to large, elliptical and heavy grains of 93001 (Figs. 10 and 11). The B1 and B2 families had green-yellow or brown colored lemma and palea and yellow or gray colored fruits, while 93001 had yellow lemma and palea and yellow fruits. Most individuals of the B1 and B2 families showed a positive and 93001 showed a negative phenol color reaction.

The characters of the *S. viridis* samples from Shangla Top and Jotal were compared to those of the B2 family. The *S. viridis* samples showed low germination rate (21.9 to 67.5%) and low germination energy (15.6 to 65.0%), except for 93039 which had rather high germination rate and germination energy. The *S. viridis* samples had short seedling leaves with anthocyan pigmentation. Range of number of days to heading, number of leaves and plant height in the *S. viridis* samples overlapped that of the B2 family. The panicle of the *S. viridis* samples was characterized by short-conical shape, brown colored anthers, short primary rachis branches without secondary branches, very long bristles and a shattering habit. Grains of the *S. viridis*

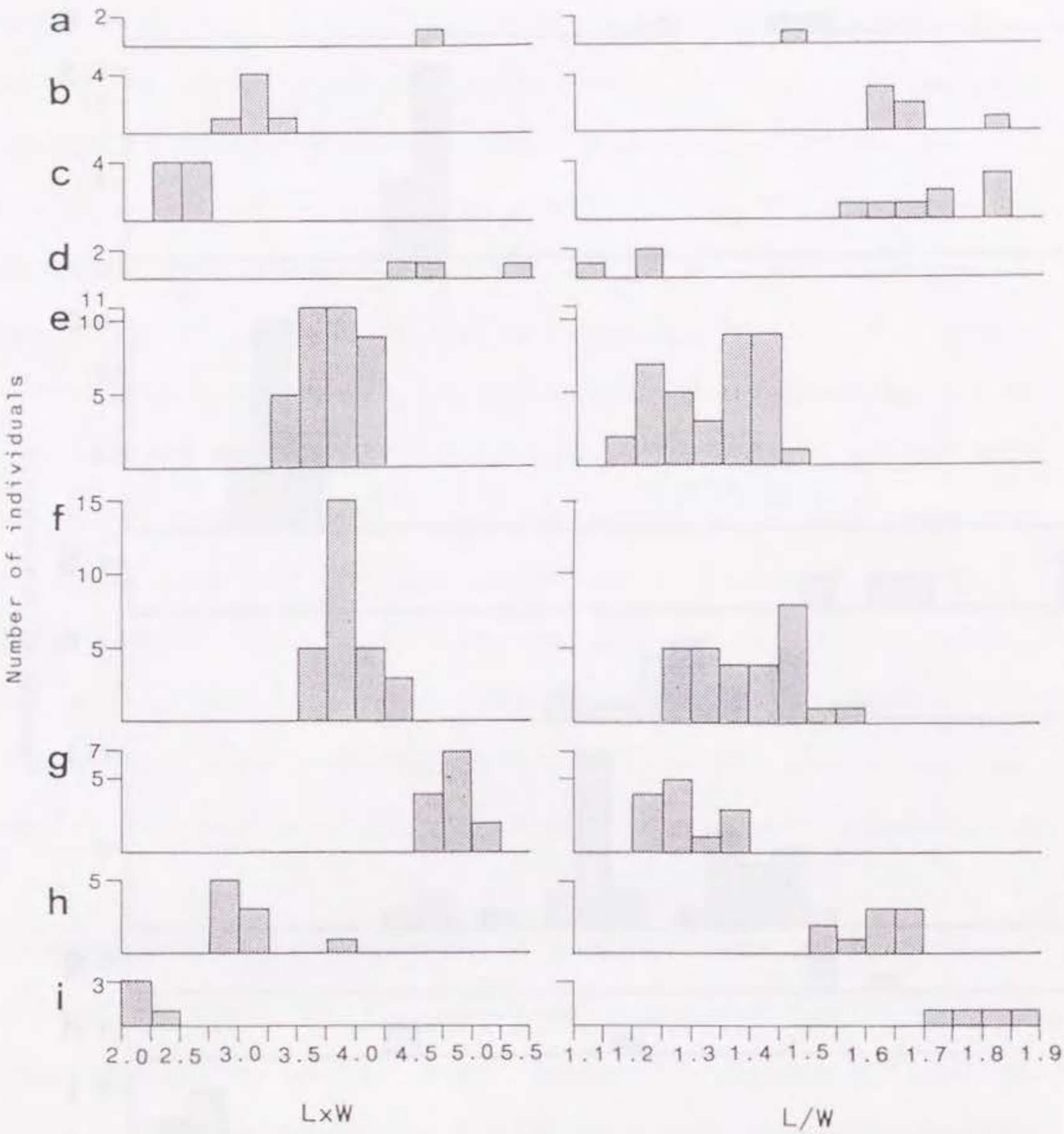

Fig. 10. Variability in the product (LxW) and the ratio (L/W) of grain length (L) and width (W) of *Setaria* samples. a: 93001, b: B1 family, c: B2 family, d:93016, 93019 and 93020, e: 93018, f: G2 family, g: 93025, h: 93026, i: *S. viridis* samples.

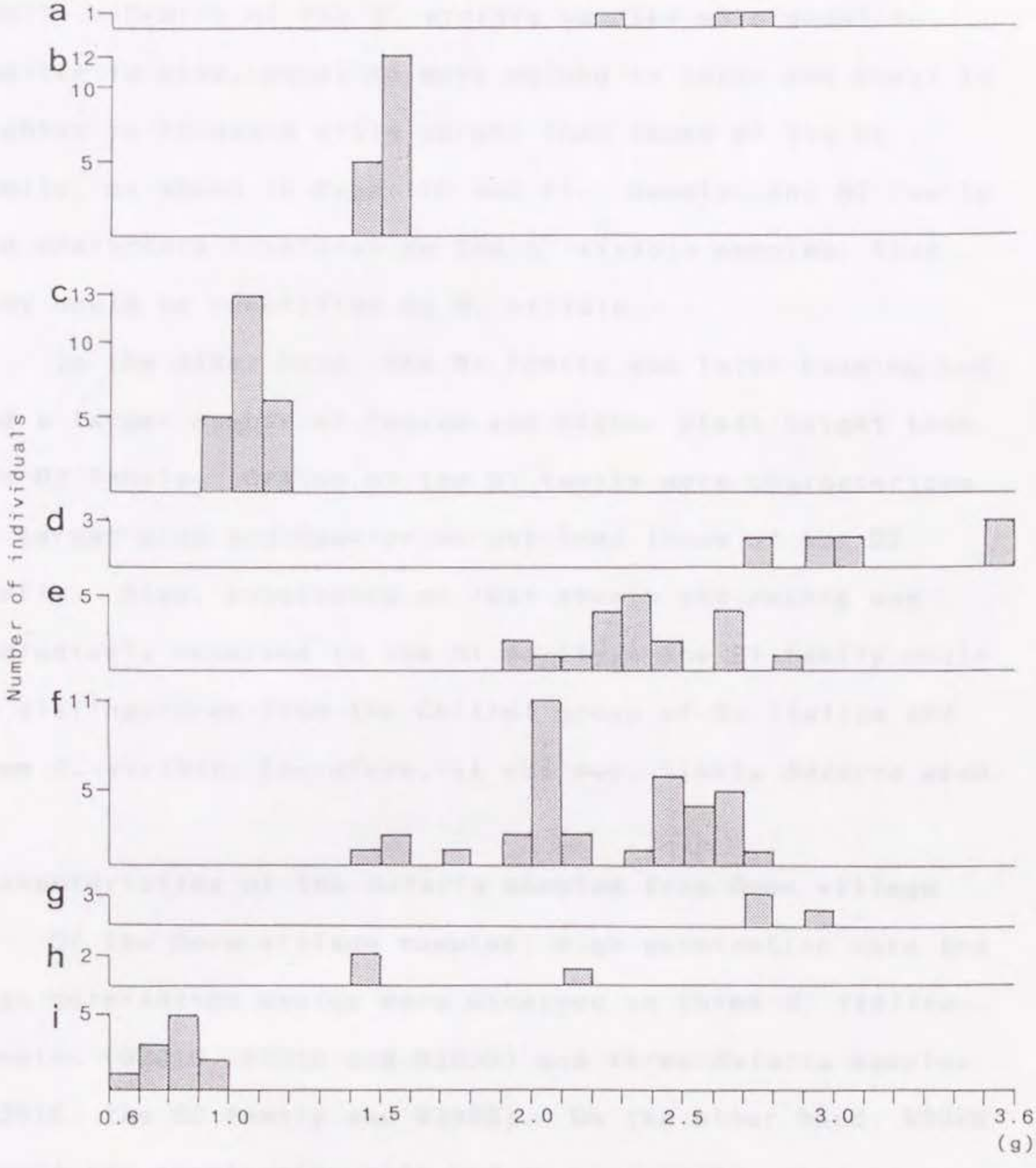

Fig. 11. Variability in thousand grain weight of *Setaria* samples. a: 93001, b: B1 family, c: B2 family, d:93016, 93019 and 93020, e: 93018, f: G2 family, g: 93025, h: 93026, i: *S. viridis* samples.

samples had brown lemma and palea and gray fruits and showed a positive phenol color reaction. Characters of the *S. viridis* samples mentioned above were also observed in the B2 family. Grains of the *S. viridis* samples were equal to smaller in size, equal to more oblong in shape and equal to lighter in thousand grain weight than those of the B2 family, as shown in Figs. 10 and 11. Namely, the B2 family had characters identical to the *S. viridis* samples; thus they could be identified as *S. viridis*.

On the other hand, the B1 family was later heading and had a larger number of leaves and higher plant height than the B2 family. Grains of the B1 family were characterized by larger size and heavier weight than those of the B2 family. Also, pubescence on leaf sheath and rachis was exclusively observed in the B1 family. The B1 family could be distinguished from the Chitral group of *S. italica* and from *S. viridis*; therefore, it was most likely *Setaria* weed.

Characteristics of the *Setaria* samples from Goon village

Of the Goon village samples, high germination rate and high germination energy were observed in three *S. italica* samples (93016, 93019 and 93020) and three *Setaria* samples (93018, the G2 family and 93025). On the other hand, 93026 showed low germination rate and low germination energy similar to the *S. viridis* samples from Shangla Top and Jotal.

The seedlings of 93018 were either with or without anthocyan pigmentation, in contrast to the seedlings of the other three *Setaria* samples which lacked pigmentation. Individuals of 93018 included *S. viridis*-like plants, the Baltistan group-like plants and some plants with characters intermediate between *S. viridis* and the Baltistan group, as shown in Fig. 12. The *S. viridis*-like plants were characterized by short plant height with a small number of leaves, early heading, Type I tillering pattern, a shattering habit, short-conical panicles with short rachis branches without secondary branches, long bristles and small and elliptical grains of light weight. The Baltistan group-like plants were characterized by taller plant height with a large number of leaves, later heading, Types II or III tillering patterns, a non-shattering habit, conical panicles with short bristles and large and round grains of heavy weight. Other individuals of 93018 had a combination of characters intermediate between *S. viridis* and the Baltistan group. They showed a wide range in number of days to heading (Fig. 7), number of leaves, plant height (Fig. 8), panicle length and grain size, shape and weight (Figs. 10 and 11). Furthermore, the 93018 sample contained two types of individuals as distinguished by anthocyan pigmentation on bristle (with or without pigmentation), anther color (white or brown), color of lemma and palea (yellow or brown), color of fruits (yellow or gray) and phenol color reaction (positive or negative).

In addition to the Types I, II and III plants, two

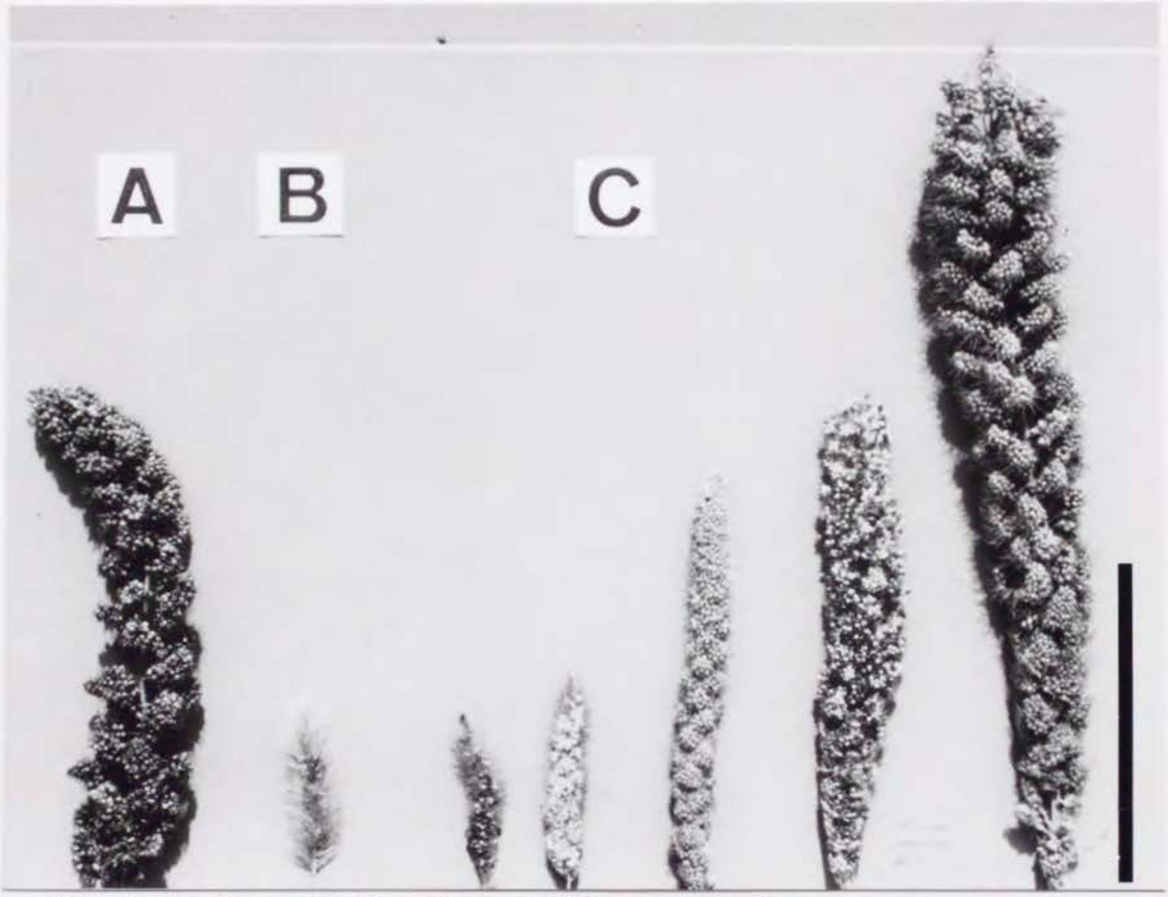

Fig. 12. Panicles of the Goon village samples.
A: the Baltistan group (93016), B: *S. viridis* (93039),
C: five individuals of 93018. Bar represents 10 cm.

other tillering patterns, Types II' and III', were found among the individuals of 93018, as listed in Table 21. Types II' and III' had tillering patterns which were similar to Types II and III, respectively, but showed some modification. Type II' plants had three to five primary tillers which developed separately on the lower part of the main culm at the early growth stage, and on the upper part at the late growth stage. Also, secondary and tertiary tillers could be observed in Type II' plants. Another newly observed tillering type, Type III', had a small number of primary tillers that developed at the upper nodes just one or two nodes below the top at the late growth stage. Secondary tillers were rarely observed in Type III' plants.

Individuals of 93018 showed semi-shattering (25.0%), as well as non-shattering (17.5%) and shattering (57.5%) types. The semi-shattering and shattering types could be distinguished from the non-shattering type by the location of the abscission layer. In the case of the non-shattering type of *S. italica*, the grain (second floret) separated from the spikelet at threshing. In the semi-shattering and shattering types, however, the whole spikelet, which was connected to the second floret, sterile lemma of the first floret and the first and second glume, separated from the pedicel at maturity. This indicated that the abscission layer formed at the base of the first glume. After shattering, small cup-like structure could typically be observed at the end of the pedicel in the semi-shattering

Table 21. Tillering characters of the Goon village samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers		Number of effective tillers		
			Lowest	Highest	Primary	2nd, 3rd & prophyll	Total
S. italica							
93016	56.9[1)]	12.6	9.2	10.6	2.4	0.0	3.0
(n=6)	1.25[2)]	0.74	0.98	0.80	0.80	0.0	1.15
	——[3)]	——	8 - 11	10 - 12	0 - 4	——	1 - 5
93018							
Type I	43.5	9.1	3.7	6.9	3.4	7.5	11.9
(n=18)	6.53	1.24	0.65	1.85	1.01	6.42	7.12
	35 - 58	8 - 12	3 - 5	5 - 11	2 - 5	0 - 18	3 - 24
Type II	42.0	8.5	4.0	6.0	2.0	0.0	3.0
(n=2)							
Type III	67.0	12.3	——	——	0.0	——	1.0
(n=3)	13.44	4.99	——	——	0.0	——	0.0
	57 - 86	7 - 19	——	——	——	——	——
Type II'	75.0	15.0	4.0	13.5	3.5	4.3	8.8
(n=4)	4.74	1.22	0.0	1.50	0.87	2.28	3.11
	69 - 81	14 - 17	4	12 - 16	3 - 5	2 - 8	6 - 14
Type III'	62.2	13.0	11.2	12.0	1.8	0.3	3.2
(n=6)	11.17	3.42	3.08	3.42	0.69	0.47	0.69
	50 - 81	9 - 19	8 - 17	8 - 18	1 - 3	0 - 1	2 - 4

Continued

n: number of plants observed, 1)mean, 2)SD, 3)range.

Table 21. Tillering characters of the Goon village samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers: Lowest	Position of nodes with primary tillers: Highest	Number of effective tillers: Primary	Number of effective tillers: 2nd, 3rd & prophyll	Number of effective tillers: Total
S. italica							
93019	55.6[1]	13.2	——	——	0.0	——	1.0
(n=9)	2.50[2]	1.55					0.0
93020	48.2	10.2	——	——	0.0	——	1.0
(n=10)	0.42	0.79					0.0
G2 family							
93021							
Type III	54.6	13.6	——	——	0.0	——	1.0
(n=7)	2.97	1.18					0.0
	49 - 58[3]	11 - 15					
Type III'	57.3	14.2	9.9	11.6	2.4	0.1	3.5
(n=23)	2.84	1.79	1.92	1.50	1.05	0.34	0.97
	49 - 61	11 - 17	5 - 12	8 - 14	1 - 6	0 - 1	2 - 7
93022							
Type III	57.2	13.8	——	——	0.0	——	1.0
(n=6)	1.67	1.34					0.0
	55 - 59	12 - 16					
Type III'	57.1	13.4	9.8	10.5	1.6	0.0	2.6
(n=11)	20.2	1.07	1.19	0.78	0.64	0.0	0.64
	54 - 61	11 - 15	8 - 10	9 - 12	1 - 3		2 - 4
93023							
Type III	52.0	11.0	——	——	0.0	——	1.0
(n=1)							
Type III'	54.4	12.2	8.5	9.4	1.5	0.23	2.7
(n=13)	3.29	1.75	2.17	2.24	0.63	0.80	0.91
	50 - 60	9 - 15	5 - 12	5 - 12	1 - 3	0 - 3	2 - 5
93024							
Type III	56.5	12.0	——	——	0.0	——	1.0
(n=2)							
Type III'	57.2	16.2	9.0	12.6	3.3	0.25	4.5
(n=12)	1.67	1.07	3.06	3.35	1.2	0.83	1.61
	54 - 60	14 - 17	5 - 13	6 - 15	1 - 5	0 - 3	2 - 8

Continued

n: number of plants observed, 1)mean, 2)SD, 3)range.

Table 21. Tillering characters of the Goon village samples

Cult. number	Number of days to heading	Number of leaves on main culm	Position of nodes with primary tillers		Number of effective tillers		
			Lowest	Highest	Primary	2nd, 3rd & prophyll	Total
93025							
Type III	53.2[1)]	12.1	—	—	0.0	—	1.0
(n=12)	2.34[2)]	3.57					
	50 - 57[3)]	12 - 16					
Type III'	54.6	13.3	8.8	10.5	2.6	0.1	3.8
(n=8)	2.91	1.09	1.56	1.50	1.41	0.33	1.56
	51 - 58	12 - 15	7 - 12	8 - 12	1 - 5	0 - 1	2 - 6
93026							
Type I	75.0	14.3	6.3	11.3	4.0	4.0	9.0
(n=3)	3.74	1.70	1.70	1.89	1.41	4.97	6.38
	71 - 80	12 - 16	4 - 8	10 - 14	3 - 6	0 - 11	4 - 18

n: number of plants observed, 1)mean, 2)SD, 3)range.

and shattering types. The semi-shattering type was characterized by delayed start of shattering in comparison with the shattering type, and the presence of a few spikelets which remained on the panicle at maturity.

Judging from the segregation of characters in 93018 individuals, it appeared that the original sample of 93018 was derived from recent natural hybridization between the Baltistan group of *S. italica* and *S. viridis*.

In contrast to 93018, the G2 family, 93025 and 93026 showed rather stable characters as follows. The G2 family and 93025 had shorter seedling leaves than the other *Setaria* samples from Goon village. The G2 family and 93025 had equal to larger number of days to heading (Fig. 7) and equal to larger number of leaves than 93019 and 93020. Two tillering patterns, Types III and III', were observed among the individuals of the G2 family and 93025 (Table 21).

The G2 family had conical panicles with short rachis branches and short bristles without anthocyan pigmentation (Fig. 13). Almost all the individuals of the G2 family (98.7%) had a shattering habit, with the exception of two semi-shattering plants. Range of grain size, shape and weight of the G2 family overlapped that of 93018 (Figs. 10 and 11). Grains of the G2 family had yellow or brown lemma and palea and yellow fruits, and showed a positive phenol color reaction.

On the other hand, the conical or cylindrical panicles of 93025 had slightly developed rachis branches and short

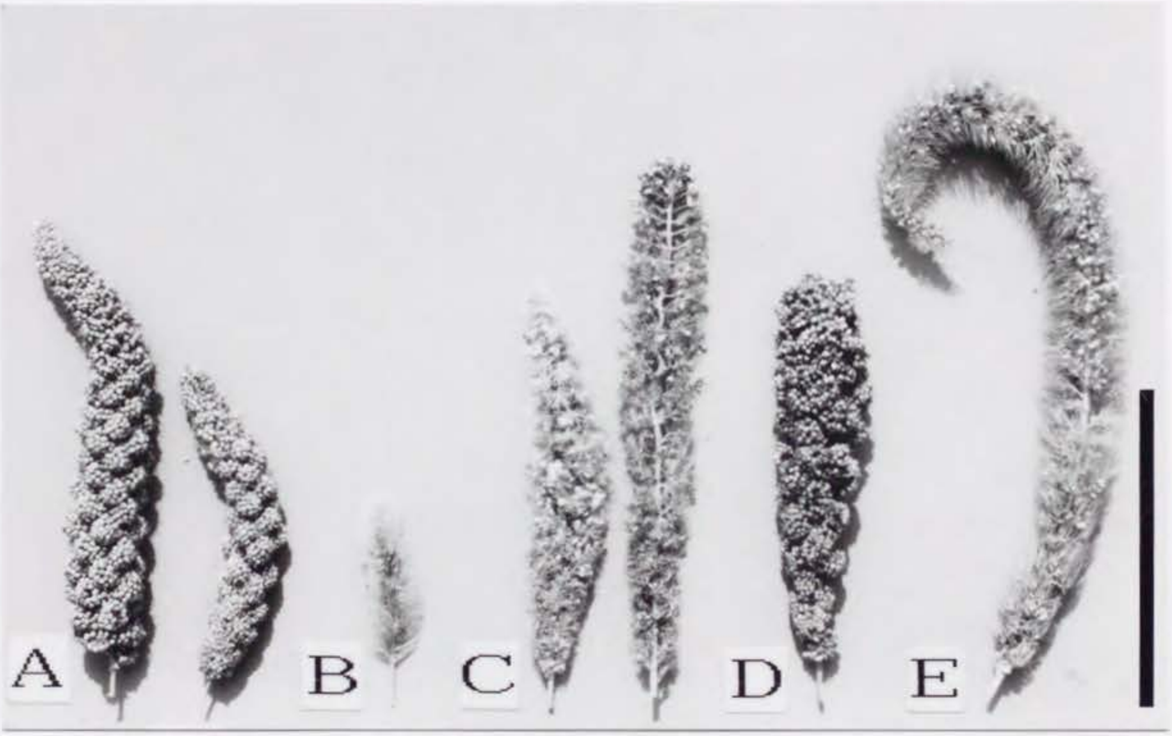

Fig. 13. Panicles of the Goon village samples.
A: the Baltistan group (93019 and 93020),
B: *S. viridis* (93039), C: G2 family (93023 and 93024),
D: 93025, E: 93026. Bar represents 10 cm.

bristles with or without anthocyan pigmentation (Fig. 13). Individuals of 93025 were composed of 2 non-shattering (8.3%), 14 semi-shattering (58.3%) and 8 shattering (33.3%) plants. Grains of 93025 were characterized by brown colored lemma and palea, yellow fruits, large size, round shape and heavy weight (Figs. 10 and 11). Of the two individuals of 93025 examined, one showed a positive and the other showed a negative phenol color reaction.

The 93026 sample was late heading (Fig. 7) and had tall plant height (Fig. 8) with many leaves on the main culm. As shown in Table 21, all the individuals of 93026 showed the Type I tillering pattern with three to six primary tillers that spread at the node of the main culm, and bore secondary and tertiary tillers as well. Panicles of 93026 were characterized by a long-conical shape bearing loosely arranged rachis branches with long bristles lacking anthocyan pigmentation (Fig. 13). Pubescence on leaf sheath and rachis was observed in 93026. All the individuals of 93026 showed a shattering habit. Grains of 93026 were the smallest, most elliptical and the lightest among the Goon village samples (Figs. 10 and 11), and had brown lemma and palea and gray fruits with a positive phenol color reaction, as did the *S. viridis* samples.

Characteristics of the G2 family, 93025 and 93026 differed from those of the Baltistan group of *S. italica* and from those of *S. viridis* and thus could be identified as *Setaria* weeds.

DISCUSSION

The *Setaria* weeds collected with the Chitral group from Bambreet village had different characteristics than those collected with the Baltistan group from Goon village.

The Chitral group, *Setaria* weed and *S. viridis* of Bambreet village showed little difference in morphological characters. They shared such common characters as early heading, short plant height, Type I tillering pattern and short conical panicles with short rachis branches. However, they could be differentiated from other samples by seedling characters, shattering habit, anther color, bristle length, color of lemma and palea, phenol color reaction and grain size, shape and weight.

It seems difficult to distinguish the appearance of the Chitral group from the *Setaria* weed and *S. viridis* at the vegetative stage and at maturity. In the Chitral District, N.W.F.P., people harvested *S. italica* by pulling the whole plants with roots from the ground. For example, one harvested bundle from Laspur village, N.W.F.P., contained 158 panicles of the Chitral group, 34 of *S. viridis* and 355 of *P. miliaceum* (Kawase and Sakamoto 1989). Three strains with a shattering habit which were recognized as the Chitral group in chapter 2 could be identified as *Setaria* weed or *S. viridis* grown with *S. italica*. The *Setaria* weed and *S. viridis* were probably associated with the Chitral group because of simultaneous harvesting. Two possibilities about the origin of the B1 family can be proposed; (1) the B1 family is midway in the domestication process from *S. viridis* to *S. italica*, and (2) the B1 family is derivative of the hybridization between the Chitral group and *S. viridis*.

In Goon village, several types of *Setaria* weeds were found. The sample of 93018 contained *S. viridis*-like plants, the Baltistan group-like plants and also plants with characters intermediate between *S. viridis* and the Baltistan group. This sample suggests that natural hybridization between the Baltistan group and *S. viridis* continually occurs in northern Pakistan.

On the other hand, the G2 family, 93025 and 93026 showed rather stable characters. The G2 family and 93025 displayed characters identical to the Baltistan group such as Types III and III' tillering pattern, conical panicles with short bristles, white anthers, yellow fruits, large and round grains of heavy weight. Individuals of 93026 showed the Type I tillering pattern, long-conical panicles and rather small and oblong grains, in contrast to the G2 family and 93025. However, 93026 could be distinguished from the *S. viridis* samples by late heading, tall plant height, white colored anthers and larger and heavier grains, which were found in the Baltistan group. It appears that the late heading of 93026 makes it suitable for harvest together with the Baltistan group.

Among the individuals of 93018 and 93025, three shattering types, shattering, semi-shattering and non-shattering, were found. According to Li et al. (1945), inheritance of grain shattering in *S. italica* is due to the two complimentary factors, S and H. The semi-shattering habit could have occurred in the Sh or sH genotypes.

Setaria weed, which was slightly taller than the Baltistan group of *S. italica* and had much slender panicles, was not found outside the *S. italica* field of Chalat village, located in the Hunza valley (Kawase and Sakamoto, 1989). According to Kawase (personal communication, 1996), *S. italica* in Baltistan was packed in a harvested bundle along with *Setaria* weeds. The *Setaria* weeds probably escaped weeding by local farmers during the vegetative stage. Some *Setaria* weeds dispersed their grains by the shattering or semi-shattering habits; others were harvested accidentally and sown again with the Baltistan group in following season.

It is concluded that the Baltistan group was associated with several types of the *Setaria* weeds that have various degrees of relatedness to the Baltistan group. It is also probable that these weeds were the result of natural crosses between the Baltistan group and *S. viridis*. The progeny of hybrids between *S. italica* and *S. viridis* may be backcrossed with *S. italica* or *S. viridis*. This would cause differentiation of many types of *Setaria* weeds, as seen in those of Goon village.

Local names of *S. viridis* and *Setaria* weeds are comprised with those of *S. italica* in Table 22. Interestingly, the Chitral group and *S. viridis* are identified by similar names in N.W.F.P.. According to Kawase (personal communication, 1996), anthocyan pigmentation on *S. viridis* is a key character by which people of Booni village distinguish it from the Chitral group. However, no information about the local names of the *Setaria* weeds could be obtained in the distribution areas of the Chitral group. It can be speculated that the farmers are not aware of the *Setaria* weeds in fields of the Chitral group. On the other hand, the Baltistan group and *Setaria* weeds that were found in the same cultivation field were correctly identified and had distinctive names.

In order to compare the *Setaria* samples from Bambreet village with those from Goon village, four main characters, namely tillering and shattering types and grain size and shape were selected based on the present observations. These four characters were considered the most ideal for comparison of the *Setaria* weeds found in the two villages. According to the combination of these four characters, the *Setaria* samples excluding 93018 were classified into two groups, as shown in Fig. 14.

The B1 family of Bambreet village and 93026 of Goon village were classified into the same group as the B2 family and the *S. viridis* samples from Shangla Top and Jotal. This group contained only samples with Type I tillering pattern, a shattering habit and small and oblong grains. Individuals

Table 22. Local names of *S. italica*, *Setaria* plants and *S. viridis*

Collection locality	Local name	Field observation and identification (landrace group)[3]
87-9-24-2[1]		
Bambreet, N.W.F.P.	krazik	*S. viridis*
	grashik	*S. italica* (the Chitral group)
87-9-27-1[1]		
Booni, N.W.F.P.	gaas	*S. italica* (the Chitral group) with anthocyan pigmentation[4]
	grass	*S. italica* (the Chitral group) without anthocyan pigmentation
87-9-28-2[1]		
Gorakumuri, Gilgit Agency	kharap	*S. viridis*
	gras	*S. italica* (the Chitral group)
2529[2]		
Gulmit Bala, Gilgit Agency	phoori	hybrid-like plant
	cha	*S. italica*
87-10-8-3[1]		
Karis, Baltistan	puli	hybrid-like plant
	cha	*S. italica* (the Baltistan group)
87-10-8-5[1]		
Kunis, Baltistan	chabilis	giant foxtail type
	cha	*S. italica* (the Baltistan group)

1)Collected and identified by Kawase and Sakamoto (1989).
2)Collected and identified by Nakagahra et al. (1990).
3)Classified in chapter 2.
4)Local people identified "gaas" as *S. viridis*.

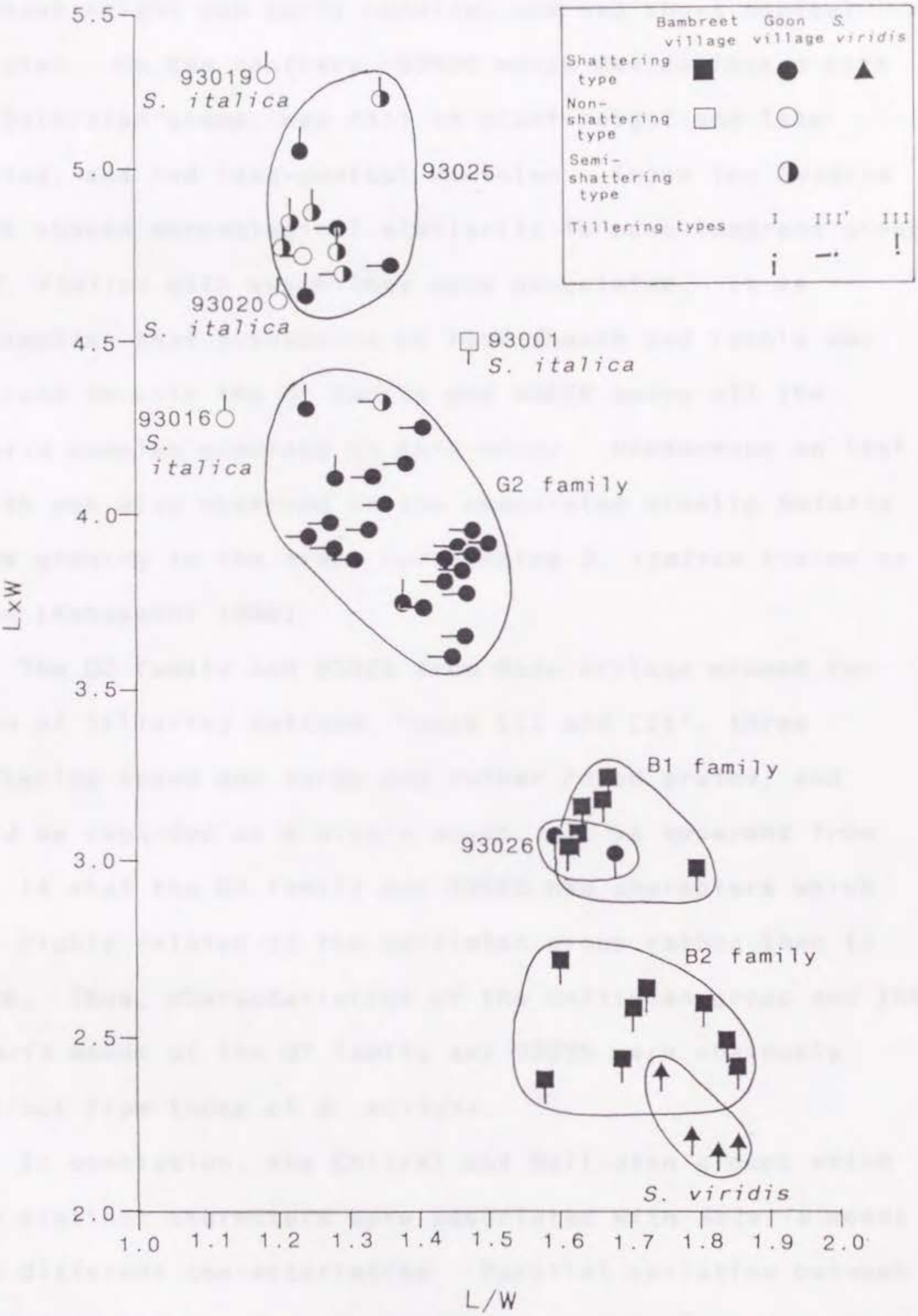

Fig. 14 Grouping of *Setaria* weeds of northern Pakistan based on grain size (LxW) and shape (L/W) and shattering and tillering types.

of the B1 family collected with the Chitral group were short in plant height and early heading, and had short conical panicles. On the contrary, 93026 which was collected with the Baltistan group, was tall in plant height and late heading, and had long-conical panicles. These two *Setaria* weeds showed morphological similarity to each landrace group of *S. italica* with which they were associated. It is interesting that pubescence on leaf sheath and rachis was observed in only the B1 family and 93026 among all the *Setaria* samples examined in this study. Pubescence on leaf sheath was also observed in the associated mimetic *Setaria* weeds growing in the areas surrounding *S. italica* fields in Japan (Kobayashi 1988).

The G2 family and 93025 from Goon village showed two types of tillering pattern, Types III and III', three shattering types and large and rather round grains, and could be regarded as a single group. It is apparent from Fig. 14 that the G2 family and 93025 had characters which were highly related to the Baltistan group rather than to 93026. Thus, characteristics of the Baltistan group and the *Setaria* weeds of the G2 family and 93025 were obviously distinct from those of *S. viridis*.

In conclusion, the Chitral and Baltistan groups which have distinct characters were associated with *Setaria* weeds with different characteristics. Parallel variation between *S. italica* and the *Setaria* weeds occurred in Bambreet village and also in Goon village. Furthermore, it is noted that there was wide variation in morphological characters among the Baltistan group, the *Setaria* weeds in Goon village and *S. viridis*, as opposed to the slight differences in morphological characters observed among the Bambreet village samples.

Chapter 5: General discussions

1). The domestication and differentiation process of *S. italica* as viewed from the distribution of landraces

S. viridis, the probable ancestor of *S. italica*, may have been gathered for a long time before the domestication of *S. italica* (Renfrew 1973). At the first step in domestication, people might plant and harvest *S. viridis* for the utilization of its grain. Repeating this step year after year, domesticated *S. italica* eventually resulted from the selection of non-shattering individuals from *S. viridis* populations. Thus, in the initial period of domestication, both *S. viridis* and *S. italica* may have been cultivated simultaneously. Then, *S. italica* gradually replaced the wild forms during the repeated cultivation. In the case of the *Setaria* remains recovered from the coprolites of Tamaulipas, there were quite a large number of grains definitely larger and fatter than the wild type. This suggested that there had been a conscious selection for grain size associated with harvesting and sowing by Tamaulipas inhabitants (Callen 1967).

As discussed in chapter 4, the Chitral group of *S. italica*, the *Setaria* weeds and *S. viridis* grown admixed in a field could be harvested together. It can be said that conditions similar to the beginning of domestication of *S. italica* are still present in the distribution area of the Chitral group in northern Pakistan.

S. italica from northern Pakistan and those from Eurasia, which showed wide variation in the number of tillers, could be classified into four tillering types, Types I - IV, as discussed in chapter 3. In addition, as revealed in chapter 4, *S. viridis* showed the Type I tillering pattern which was genetically a dominant character. While Types II and III tillering patterns were clearly distinguished from Type I and were genetically recessive. Consequently, the differentiation of *S. italica* from *S. viridis* may have occurred as follows: *S. italica* of Type I that retained high tillering capacity was probably the first domesticated type, and Types II and III were subsequently derived from Type I by obtaining strong apical dominance.

As clarified in chapter 2, three groups of *S. italica* with distinctive characters are distributed separately in northern Pakistan. Of the three groups, the Chitral group had characteristics similar to *S. viridis*. These included the Type I tillering pattern with a large number of tillers, very early heading with a small number of leaves, short plant height and short-conical panicles with long bristles. The same characteristics were also observed in the Afghan strains. Moreover, morphological similarity between the Chitral group and *S. viridis* was clearly shown in chapter 4. The only substantial difference between the two is that *S. viridis* showed a shattering habit and seed dormancy and had light grains of small size and oblong shape, while the

Chitral group and the Afghan strains showed a non-shattering habit and low seed dormancy and had heavy grains of large size and elliptical shape. In other words, the Chitral group and the Afghan strains represents the most primitive type of domesticated *S. italica*.

On the other hand, the characteristics of the Baltistan group were clearly distinct from those of *S. viridis*, as discussed in chapter 4. Also, the Types II and III strains from Eurasia had differentiated characters such as number of days to heading, number of leaves, plant height, panicle shape, grain size, shape and weight and the waxiness of endosperm starch.

Since the three tillering types, Types I - III, were not evenly distributed over Eurasia and the most primitive type of *S. italica* was found in northern Pakistan and Afghanistan, the following geographical origin and dispersal routes of *S. italica* are suggested. Namely, *S. italica* of Type I was domesticated in South Asia and neighboring areas where Type I, including the Chitral group and the Afghan strains, and Types II and III were all present; from there Type I strains were dispersed throughout Southwest and Central Asia and Europe where Type I is abundantly found. Thereafter, Types II and III strains were differentiated from Type I and then were spread over Southeast and East Asia, where Types II and III are mainly distributed. This view is also supported by the evidence that genetically less specialized landrace groups were distributed in the area ranging from Afghanistan to India (Kawase and Sakamoto 1987).

2). Origin and differentiation of associated *Setaria* weeds in northern Pakistan

Associated *Setaria* weed forms have been reported in several places in East Asia. *S. viridis*-like weeds growing with *S. italica* in the western part of the Korean peninsula was reported by Sawamura (1951). Associated mimetic *Setaria* weeds were collected at villages in Nara, Niigata and Nagano Prefectures, Japan by Kobayashi (1988). He reported that differentiation of the associated weeds occurred in the permanent fields in the vicinity of villages rather than in the shifting cultivation fields. *Setaria* weeds, which showed characters intermediate between *S. italica* and *S. viridis*, were frequently found both inside the *S. italica* fields and along roadsides far from fields in the western part of Cheju Island, Korea (Ochiai 1996a).

Plant taxonomists distinguished the associated *Setaria* weed forms from *S. viridis*, and identified them as *S. pycnocoma* (Steudel) Henrard (Nakai 1939), *S.* x *pycnocoma* (Steud.) Henrard ex Nakai (Osada 1993), *S. viridis* subsp. *pycnocoma* (Steud.) Tzvel. (Tsvelev 1976, Chen 1990), *S. gigantea* (Franch. et Sav.) Makino (Makino 1911), *S. viridis* var. *gigantea* Matsumura (Lee 1966) or *S. viridis* var. *major* (Gaud.) Posp. (Darmency et al. 1987). The origins of those associated *Setaria* weed forms are, however, still under debate. Willweber-Kishimoto (1962) suggested that *S.* x *pycnocoma* was a product of natural hybridization between *S. italica* and *S. viridis*. She classified *S. pycnocoma* from an *S. italica* field in Kagoshima Prefecture, Japan into three morphological types: *italica* type, *viridis* type and intermediate type. Tsvelev (1976) was inclined to think that *S. viridis* subsp. *pycnocoma* is a transitional step between *S. viridis* and *S. italica*. According to Darmency et al. (1987), *S. viridis* var. *major* could have resulted from a wild x crop hybridization.

As indicated in chapter 4, characteristics of the *Setaria* weeds collected at Bambreet village in northern Pakistan were different from those of the *Setaria* weeds in Goon village. Interestingly, parallel variation between *S. italica* and associated *Setaria* weeds could be recognized in each village based on the present study. Also, the Goon village samples were composed of several types of *Setaria* weeds. However, no *Setaria* weeds collected from these two villages had characters identical to *S. viridis* subsp. *pycnocoma* as described by Tsvelev (1976), or *S.* x *pycnocoma* reported by Osada (1993).

As listed previously, the associated *Setaria* weed forms growing in several areas of Eurasia have been identified by authors using different scientific names. However, it has not been confirmed that they are identical taxon. It can hardly be concluded that only one associated *Setaria* weed form with a single origin dispersed with *S. italica* throughout Eurasia. Rather, it is possible that the associated *Setaria* weed forms originated independently through natural hybridization between *S. italica* and *S. viridis* in their overlapping areas of distribution. Therefore, an associated *Setaria* weed form may have different characteristics depending on the *S. italica* with which it grows, as seen in the *Setaria* weeds from the two villages in northern Pakistan. The establishment of various types of associated *Setaria* weed is enhanced by gene flow between *S. italica* and *S. viridis*. It is evident that *S. italica*, *S. viridis* and their associated *Setaria* weeds compose a crop-weed complex in northern Pakistan. Similar cases were reported for two African millets, *Sorghum bicolor* (Harlan et al. 1973) and *Pennisetum americanum* (Brunken et al. 1977).

Summary

Setaria italica (L.) P. Beauv. (foxtail millet) is a summer annual cereal crop and is distributed throughout Eurasia. In 1987, landraces of *S. italica*, *S. viridis* and unidentified *Setaria* plants were collected in the mountain areas of northern Pakistan.

The seventy-one strains of *S. italica* from northern Pakistan were classified into three groups: the Chitral, Baltistan and Dir groups, by combination of characters. The Chitral group was characterized by early heading and very short plant height, a large number of tillers and short conical panicles with long bristles. The Baltistan group was early heading and had short plant height, a non-tillering habit and a conical panicle with short bristles. The Dir group was intermediate to late heading and had tall plant height and a large number of tillers with long-conical panicles. Orange colored anthers and elliptical grains with lucid lemma and palea were observed in the Chitral and Dir groups, while the Baltistan group had white anthers and round shaped non-lucid grains. Strains with a negative phenol color reaction were frequently found in the Chitral and Baltistan groups. The Dir group contained both positive and negative types of phenol color reaction. Pollen and seed fertility of F_1 hybrids indicated that the Chitral and Baltistan groups are composed of genetically differentiated strains, despite the shared characteristics within the

groups. Compared with other Eurasian strains, the distinct characters of the three groups were similar to those of strains from different regions of Eurasia. Also, the distribution areas of the three groups in northern Pakistan were clearly isolated from each other.

Detailed analysis of tillering in *S. italica* was carried out. The strains were classified into four tillering types, Types I - IV. Type I strains had a large number of tillers with many primary tillers on the main culm, and also secondary and tertiary tillers. Type II strains produced only one or two primary tillers and no secondary tillers. Type III strains showed a non-tillering habit. Only one strain collected from Kochi Prefecture, Japan was Type IV, and had characteristics intermediate between Types I and II. *S. viridis* showed the Type I tillering pattern which was genetically a dominant character, while Types II and III tillering patterns were recessive. Almost all the strains from Europe and Central and Southwest Asia were Type I. Strains of Types II and III were frequent in Southeast and East Asia, while those of Type I were rare. Types I, II and III strains were all present in South Asia. A high diversity of tillering types is thus apparent in South Asia.

Since the Chitral group and the Afghan strains represented the most primitive types of *S. italica* and the three tillering types of *S. italica* were not evenly distributed over Eurasia, a geographical origin and dispersal routes for *S. italica* could be suggested.

Characteristics of unidentified *Setaria* samples as well as the Chitral and Baltistan groups and *S. viridis*, collected at Bambreet and Goon villages in northern Pakistan, were compared. The Bambreet village samples were composed of the Chitral group of *S. italica*, a *Setaria* weed and *S. viridis*. They could be distinguished from each other by seedling characters, a shattering habit and grain size, shape and weight. However, they showed little difference in such morphological characters as early heading, short plant height, Type I tillering pattern and short conical panicles with short rachis branches. Two possibilities concerning the origin of the *Setaria* weed in Bambreet village could be proposed; (1) the *Setaria* weed is midway in the domestication process from *S. viridis* to *S. italica*, and (2) it is derived from hybridization between the Chitral group and *S. viridis*. In Goon village, several types of *Setaria* weeds were found in fields of the Baltistan group. One *Setaria* sample contained *S. viridis*-like plants, the Baltistan group-like plants and also plants with characters intermediate between *S. viridis* and the Baltistan group. Characters of the other three *Setaria* weeds showed various degrees of relatedness to the Baltistan group. It is probable that *Setaria* weeds in Goon village resulted from natural hybridization between the Baltistan group and *S. viridis*, following backcrosses.

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