Variations of Growth-Period of Italian Millet Strains, *Setaria italica Beauv.* and their Response to Day-Length and Temperature

1. Changes of Growth-Period of Main Standard Varieties in Japan due to the Different Seeding Dates

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Introduction

Italian millet was introduced, in ancient times, to Japan from China, and it had been the most important crop among the upland field-ones in old years. This crop was cultivated about 250,000 ha. in Japan in 1900. But, the cultivating-area was reduced year after year, to have left only the area of 15,000 ha. in 1961. Recently, the local varieties are on the verge of being lost, even in this district, one of the main producting districts in Japan, with the reducing number of cultivators of this crop.

With the purpose of reserving the strains of this crop as breeding material, collection of it has been carried out since 1949, and now we have the reserve, counting about 500 strains gathered from different districts, both native and foreign.

In Japan Italian millet varieties are seeded almost all the year round; namely, at early week in May, in Hokkaido and Tōhoku; at late week in May, in Nagano; at early week in June, in Hiroshima; at early week in July, in Ibaragi; at middle or late week in June, in Nagasaki and Kumamoto; at middle and late week in July or early week in August, in Kagoshima; at middle week in January, in Amami-ooshima and at late week in December, in Okinawa. Generally, the varieties in Japan are classified into the spring-type and the summer-type, according to their seeding-times. The authors[2,3] reported that spring-typed varieties were less sensitive to day-length than summer-typed ones.

The growth-period-variations of main standard-varieties in Japan, collected in 1949 and 1950, the relationships between their districts and their responses to day-length and to temperature are reported in this paper.

Material and Method

Fifty varieties, consisting of two from Aomori, six from Akita, fourteen from Nagano, five from Nagasaki, seven from Kumamoto and sixteen from Kagoshima, were used in this experiment. They were spared to our laboratory, from the agricultural experimental stations of the respective prefecture. The varieties were seeded, six times, at different dates, at about one-month-interval, in 1963; namely, on April 10,

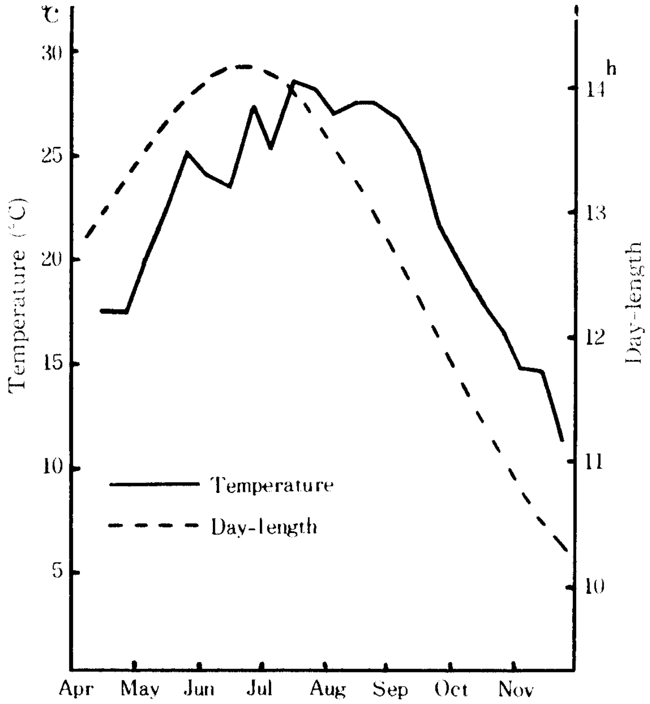

Fig. 1. Changes of the mean temperature and day-length during the experimental period.

May 18, June 10, July 13, August 12, and September 10, respectively. After germination, the plants were thinned in, about 10 *cm* distance apart, each other, and about thirty plants of the respective variety were cultivated. Heading-dates and the number of leaves of main stem of all plants of the respective variety were recorded. For the purpose of preventing the number from becoming indistinguishable, the leaves were marked with paint on each four leaves, counting from the lowest. The whole data were illustrated by the average-value in the whole plants used in the respective varieties.

Results

1. Variations of the growth-period

Frequency-distributions of the growth-period-variations, in days, from seeding to heading of the respective variety on different seeding dates, are shown in Table 1. The number of days from seeding to heading of the respective variety generally became shorter as the seeding-dates delayed from April to August. Exceptionally, five varieties showed the shortest growth-period in seeding in July, but the growth-periods of these five varieties hardly differed from those of the varieties seeded in August. In those seeded in September, however, the growth-periods of all the varieties were noted to have become longer again. Concerning the variations of growth-period among the varieties seeded on the same date, those seeded in April were largest, becoming smaller as the seeding dates became later, reaching smallest in those seeded in August. While, those seeded in September became larger again. This resulted from the fact that the growth-period-shortening-degrees differed in the different varieties. Generally, the

Table 1. Frequency-distributions of varietal variation of growth period on different seeding dates.

Seeding dates		Number of days of growth-period 30	40	50	60	70	80	90	100	110	120	130	140	150	160	∞	Total
April	10			1	7	8	11	9	2	1	3	5	2	1			50
May	18		4	18	11	5	3	6	2	1							50
June	10		10	24	4	8	2	2									50
July	13	6	31	11	2												50
Aug.	12	20	26	4													50
Sept.	10		2	6	9	11	9	5								7	49

note ; ∞ : un-headed

Table 2. Frequency-distributions of geographical variations of the shortest growth-period.

Disdtricts	Latitude (°N)	The most shortest growth period 30	35	40	45	50	55	Total
Aomori	42-39		2					2
Akita	42-39	3	2	1				6
Nagano	37-35	3	5	5		1		14
Nagasaki	34-33		2		3			5
Kumamoto	33-32		2	4	1			7
Kagoshima	32-31		1	5	7	3		16
Total		6	14	15	11	4		50

varieties showing longer growth-period in seeding in April, showed larger degree of shortening of growth-period, showing greater variations of growth-periods in accordance with the seeding dates. In spite of these facts, the number of days of growth-period of the varieties seeded in April, correlated with those seeded in August. In seedings in April and May, un-headed plants were observed, in different degrees, in some varieties with longer growth-period ; and also in seeding in September, the varieties heading through all the plants were rather fewer, and seven varieties failed to head through all the plants. Above mentioned results show that seeding in August 12 gave the most favourable environment to the shortening of growth-period in almost all the varieties used. In order to clear the effect of day-length and temperature to the growth-period of the varieties, notice was taken on the shortest growth-period in the respective varieties in this experiment. Frequency-distributions of the geographical variation of the shortest growth-period of the respective varieties are shown in Table 2. Generally, varieties from the higher-latitude-districts showed shorter growth-period than those from the lower-latitude-ones.

2. Sensibility to day-length

Seasonal changes of day-length and temperature are the important factors affecting to the variations of growth-period. Oka[4] showed that the sensibility of rice-plant to

Table 3. Frequency-distributions of geographical variations of the sensibility to day-length.

Districts	Latitude (°N)	Sensibility 0	5	10	15	20	25	30	35	40	∞	Total 2
Aomori	42-39	1									1	2
Akita	42-39	4	1								1	6
Nagano	37-35	10		3		1						14
Nagasaki	34-33	3	1	1								5
Kumamoto	33-32	2	2	3								7
Kagoshima	32-31	2	1	4	2	1	1		1		4	16
Total		22	5	11	2	2	1		1		6	50

day-length could be expressed in T. D. M. (Tangent Day Minute). In this paper, the sensibility to day-length is expressed by the ratio of the changing of growth-period counted in days between the two successive seeding-dates to the changing of natural day-length counted in minutes (30 days before the heading in the respective variety) between the two; and the sensibility to day-length of the respective variety is decided by the largest value of the five values observed among the six seeding dates. Of course, some considerations should be paid about the shortening effect of growth-period given by the rising of temperature, from spring to summer. Frequency-distributions of geographical variations of the sensibility to day-length in the varieties, are shown in Table 3. As above mentioned, the expressed sensibility should naturally be expected to contain the effect of the rising of temperature. But, in spite of that, the frequency-distributions showed an interesting tendency, namely, the varieties from higher latitude-districts, Aomori and Akita, showed generally lower sensibility and some of those from lower-latitude-district, Kagoshima, showed higher sensibility. Two varieties from Aomori and Akita showed higher sensibility. As these varieties did not show so large a change of growth-period in any seeding-date, these values may be looked upon showing high sensibility-values, basing on the agreement of two day-length of 30 days before heading in two successive seedings before and after the summer solstice.

3. Critical day-length

The average day-length of 30 days before heading, between the two successive seedings showing the highest sensibility-value to day-length, was called the critical day-length of the respective variety. Frequcncy-distributions of the geographical variation of critical day-length for the most radical changes of the growth-period are shown in Table 4. All varieties from higher latitude showed longer critical day-length covering over 14 hours. The day-length covering over 14 hours is the day-length from early week in June to middle week in July in this district, as shown in Fig. 1. Namely, flower-formation of these varieties were accelerated in the longer day-length near to the summer-solstice-day-length. On the other hand, ten varieties from Kagoshima showed shorter critical day-length. The shortest critical day-length in the table is the day-length in middle week in August, in this district. These data show that day-length from middle week in July to middle week in August after summer-solstice is

Table 4. Frequency-distributions of geographical variation of critical day-length for the most radical change of growth-period.

Districts	Latitude (°N)	13h 25min	30	35	40	45	50	55	14h 0	5	10	15	Total
Aomori	42–39								1		1		2
Akita	42–39								3		3		6
Nagano	37–35									4	10		14
Nagasaki	34–33									2	3		5
Kumamoto	33–32										7		7
Kagoshima	32–31	1		2			5	2	1		5		16
Total		1		2			5	2	5	6	29		50

especially important to the flower-initiation for the varieties from Kagoshima.

4. Sensibility to temperature

Average-temperature from seeding to heading of the respective variety with different seeding-dates was calculated. And the ratio of changing of growth-period in days to that of average-temperature in degrees between the two successive seedings was calculated. The largest value of those ratio among the five ratios in the six seedings was considered to indicate the sensibility to temperature of the respective variety. The average-temperature between the successive seedings with the largest value, was considered to be the temperature showing the highest rate of the shortening of the growth-period of the respective variety through the rising of temperature. Frequency-distributions of the geographical variations of sensibility to temperature, are shown in Table 5. The variety from higher-latitude-districts showed sensibility lower than those from higher latitude-districts which showed sensibility lower than those from the lower latitude-ones. Some varieties from Kagoshima showed especially high sensibility. The sensibility to temperature calculated by the above mentioned method contains the effect of day-length. In fact, some of the varieties highly sensitive to temperature were also sensitive to day-length. This probably shows that there are some varieties which may be strongly accelerated in flower-formation both by short day-length and by high tem-

Table 5. Frequeucy-distributions of geographical variation of the sensibility to the average temperature during growth-period.

Districts	Latitude (°N)	Sensibility 0	5	10	15	20	25	30	35	45	50	Total
Aomori	42–39		1	1								2
Akita	42–39		4	1	1							6
Nagano	37–35		4	8		2						14
Nagasaki	34–33			2	2			1				5
Kumamoto	33–32			3	3				1			7
Kagoshima	32–31			4	1		2	4	3		2	16
Total			9	19	7	2	2	5	4		2	50

Table 6. Frequency-distributions of geographical variation of the average-temperature during growth-period showing the largest shortening rate of growth-period.

Distrists	Latitude (°N)	Temperature (°C)													Total
		22		23		24		25		26		27		28	
Aomori	42-39		1		1										2
Akita	42-39		2		2								2		6
Nagano	37-35		1		4				1		3		5		14
Nagasaki	34-33				3						2				5
Kumamoto	33-32				3		1				3				7
Kagoshima	32-31				3		2		1		10				16
Total			4		16		3		2		18		7		50

Table 7. Frequency-distributions of geographical variation of sensibility to average-temperature during flower initiation stage showing the largest shortening rate of growth-period.

Districts	Latitude (°N)	Sensibility															Total
		0		30		60		90		120		150		180		∞	
Aomori	42-39		2														2
Akita	42-39		3		2								1				6
Nagano	37-35		10		3				1								14
Nagasaki	34-33		1		1		2									1	5
Kumamoto	33-32		4		1		2										7
Kagoshima	32-31		2		1		1		4		1				2	5	16
Total			22		8		5		5		1		1		2	6	50

Table 8. Frequency-distributions of geographical variation of the average temperature during flower-initiation-period showing the largest shortening rate of growth-period.

Districts	Latitude (°N)	Temperature (°C)															Total
		22		23		24		25		26		27		28		29	
Aomori	42-39				1		1										2
Akita	42-39				2		3						1				6
Nagano	37-35		1		1		8		1				3				14
Nagasaki	34-33						1				1		3				5
Kumamoto	33-32						2		1		3		1				7
Kagoshima	32-31						2		1		1		9		3		16
Total			1		4		17		3		5		17		3		50

perature. Frequency-distributions of the geographical variation of the temperature showing the largest value of shortening-rate of growth-period of the respective variety through the rising of temperature are shown in Table 6. Varieties from Aomori showed lower temperature and, some ones from Akita and Nagano showed lower temperature and the others showed higher temperatures. Varieties from Nagasaki, Kumamoto and Kagoshima showed intermediate temperature. To clear the effect of temperature during the flower-initiation-stage for growth-period, the average temperature from 35 days to 15 days before heading in the respective variety was calculated and sensibility-value or sensibility-temperature of the respective variety was calculated, too, by the same method for the whole growth-period. Frequency-distributions of the geographical variations of the sensibility-value and sensibility-temperature in the flower-initiation-stage are shown in Tables 7 and 8. Generally, the distributions of these values and temperature showed the same tendency as those for the whole growth-period.

5. Relationship between the reduced number of days of growth-period and the reduced number of leaves

The number of leaves of main stem in plants is sometimes considered to be an index of the developmental growth. Relationship between the reduced number of leaves of main stem and the reduced number of days of growth-period in the shortest growth-period compared with the growth-period in April-seeding in the respective variety are shown in Table 9. This table shows the fact that some of the varieties with the smaller number of the reduced days have the increased number of leaves; namely, some varieties increased the number of leaves of main stem in spite of the shortening of growth-period in summer-seeding, compared with that in spring-seeding. Geographical variations of the reduced number of leaves in the summer-seeding are shown in Table 10.

Table 9. Relationship between the reduced number of days of growth-period and the reduced number of leaves of main stem in summer-seeding compared with that in April-seeding.

Reduced number of days of growth period	Reduced number of leaves −8 – −6	−6 – −4	−4 – −2	−2 – 0	0 – 2	2 – 4	4 – 6	6 – 8	8 – 10	Total
20–30				2						2
30–40		1	3	4	3					11
40–50	1	1	5	6	3	1				17
50–60			1	3	3					7
60–70					1	1				2
70–80						1	4			5
80–90							1	2	1	4
90–100								1	1	2
Total	1	2	9	15	10	3	5	3	2	50

Table 10. Frequency-distributions of geographical variation of the reduced number of days of growth-period in summer-seeding compared with those in spring-seeding.

Districts	Latitude (°N)	Reduced number of leaves −8	−6	−4	−2	0	2	4	6	8	10	Total
Aomori	42-39			1		1						2
Akita	42-39				4	2						6
Nagano	37-35	1	1	3	8	1						14
Nagasaki	34-33		1		1	2	1					5
Kumamoto	33-32			2	2	2	1					7
Kagoshima	32-31			1	2	2	2	4	3	2		16
Total		1	2	7	17	10	4	4	3	2		50

Table 11. Relationship between critical day-length and the reduced number of leaves of main stem.

Critical day-length		Reduced number of leaves −8	−6	−4	−2	0	2	4	6	8	10	Total
13h	25min											
	30								1			1
	35											
	40									2		2
	45											
	50											
	55					1	1	2	2			6
14h	0					2	1	1				4
	5							1				1
	10	1	1	1	1	1	1					6
	15		2	6	15	6	1					30
Total		1	3	7	16	10	4	4	3	2		50

Many varieties from higher-latitude-districts increased the number of leaves in summer-seeding when they showed the shortest growth-period. As the varieties from higher latitude-districts had longer critical day-length than those from lower ones, the relationship between the critical day-length and the reduced number of leaves of main stem of the varieties is shown in Table 11. Many varieties having longer critical day-length increased the number of leaves in summer-seeding, compared with those in spring-seeding.

Discussion

Total temperature after seeding in August-seeding, when almost all varieties showed the shortest growth-period, was always lower than that in July-seeding during the whole growth-period, shown in Table 12. So, it seems that the shortest growth period of the respective variety realized in August-seeding not only depends on the higher temperature but also on the shorter day-length in summer. It was reported that the number of days from seeding to heading of the late rice-varieties were controlled by higher temperature in summer, but little effected by natural day-length when they were sown on late season (July 12)[1]. But, according to the above results, it seems that the number of days from seeding to heading in almost all the varieties of Italian millet were affected by the natural day-length when they were sown on late season (August 12). Especially, the number of days from seeding to heading of the strains from Kagoshima showing critical day-length shorter than 14 hours, are largely affected by the natural day-length of the middle or late week in August. In fact, some varieties with shorter critical day-length from Kagoshima headed on almost the same date in September, whenever they were sown except September. The number of days from seeding to heading in Italian millet varieties reduced when they were sown in summer-season, but the number of leaves of the main stem of the varieties which showed smaller number of days from seeding to heading was not reduced or rather increased. In spring-seeding, it would be, more or less, the short-day-length-condition for the varieties which have longer critical day-length. So, the growth-period of these varieties under natural short-day-length for them, would rather be shortened by the acceleration of developmental growth, based on the rising of temperature in summer-seeding. So, the result of Table 11 seems to show that long-critical-day-length varieties would increase the number of leaves and decrease the number of days of growth-period based on the acceleration of developmental growth by the rising of temperature in summer-seeding under the natural-short-day-length for them from spring to summer, because they were depressed more largely in the developmental growth by the lower temperature, on the other hand, shorter-critical-day-length-varieties decreased both the number of leaves and the number of days of growth-period, when they encountered natural-short-day-length for them in late summer season, because they are depressed only in the flower-initiation by natural long-day-length for them for the time, not by the lower temperature.

Table 12. Changes of total temperature during the growth-period after different seedings.

Number of days after seeding	Seeding date					
	Apr. 10	May 18	Jun. 10	Jul. 13	Aug. 12	Sept. 10
10	175	249	235	284	275	251
20	348	488	506	564	549	468
30	545	723	758	833	815	661
40	768	994	1042	1108	1066	840
50	1017	1246	1322	1382	1283	1006
60	1256	1530	2591	1648	1476	1155

Failing in heading in some of the varieties sown on September, probably depends on the lower temperature, because the day-length in the time were shorter than the critical day-length through all the varieties used. These results seem to show that the heading of some of the Italian millet varieties need somewhat higher temperature as well as short day-length in summer. And also, failing in heading in some of the varieties with shorter critical day-length than 14 hours from Kumamoto and Kagoshima when they were sown on April or May, probably, depends on the result that they were delayed in their heading by the depressing of their developmental growth by the low temperature at the early stage, and in flower-formation, by the long day-length at the later stage. As the above photo-sensitive varieties, by nature, have long growth-period even in summer-seeding, the depressing effect of the low temperature and long day-length to heading of the varieties would be more strengthened.

Summary

1. Fifty main standard varieties collected from the different districts in Japan were seeded six times at about one-month-interval from April 10 to September 10.

2. Growth-periods of almost all the varieties gradually became shortened as seeding dates were delayed and became shortest in August-seeding, but the growth-periods became longer again in September-seeding.

3. The shortest growth-periods of the varieties from higher latitude-districts were shorter than those of the varieties from lower ones.

4. The varieties from higher-latitude showed lower sensibility to the day-length and those from lower ones, higher sensibility.

5. Critical day-length of the varieties from higher latitude-districts was longer than those of the varieties from lower ones.

6. The varieties from higher latitude-districts showed lower sensibility to day-length than those from higher ones.

7. The temperature showing the largest shortening-rate of growth-period of the varieties from higher latitude-districts was lower or higher than those of the varieties from lower ones.

8. Some of the varieties increased the number of leaves of main stem in spite of the shortening of growth-period in summer-seeding, compared with those in spring-seeding. Generally, the varieties from higher latitude-districts increased the number of leaves in summer-seeding.

9. The varieties with longer critical day-length increased the number of leaves of main stem when they shortened the growth-period in summer-seeding, compared with those in spring-seeding.

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