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INDIRECT SELECTION FOR GRAIN YIELD, GENOTYPE x ENVIRONMENTAL INTERACTIONS AND ADAPTABILITY OF THE

IMPROVED POPULATION IN PEARL MILLET

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1998

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BY

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A DISSERTATION

SUBMITTED TO THE DIVISION OF AGRICULTURE GRADUATE SCHOOL KYUSHU UNIVERSITY FOR THE FULFILLMENT OF THE PHILOSOPHY OF DOCTOR DEGREE OF AGRICULTURE IN AGRONOMY

LABORATORY OF CROP SCIENCE.

DEPARTMENT OF AGRONOMY

JULY 1998

This research was conducted from October 1995 to June 1998 in the graduate school of division of Agriculture, Kyushu University. Parts of the contents were published or are preparing for publication;

1. Totok Agung Dwi Haryanto and T. Yoshida 1996. Performance and interrelationship among several characters of pearl millet (*Pennisetum tyhoideum* Rich.) population. J. Fac. Agr. Kyushu Univ. 41:1-9.

 Totok Agung Dwi Haryanto, T. K. Shon and T. Yoshida 1997. Selection for low temperature germination of pearl millet (*Pennisetum tyhoideum* Rich.) J. Fac. Agr. Kyushu Univ. 41:141-150.

1. Totok Agung Dwi Haryanto, T. K Shon and T. Yoshida 1998. Genetic gain and heritability of seedling characters selected at a low temperature in pearl millet (*Pennisetum tyhoideum* Rich.). Plant Prod. Sci.1(1):47-51.

4. Totok Agung Dwi Haryanto, T. K. Shon and T. Yoshida 1998. Effect of selection for yield components on grain yield in pearl millet (*Pennisetum tyhoideum* Rich.). Plant Prod. Sci. 1(1):52-55.

5. Totok Agung Dwi Haryanto, N. D. Can, T. K. Shon and T. Yoshida 1998. Response to early spring planting in several genotypes of pearl millet (*Pennisetum tyhoideum* Rich.). J. Fac. Agr. Kyushu Univ. 43:325-335.

6. Totok Agung Dwi Haryanto, T. K Shon and T. Yoshida. 1998. Grain yield and its components of genotypes selected for low temperature germination and the genotype x environment interaction in pearl millet (*Pennisetum tyhoideum* Rich.). Jpn. J. Trop. Agr. (submitted).

7. Totok Agung Dwi Haryanto and T. Yoshida 1998. Recurrent election effect, genetic gain and genetic correlations for yield and yield components in pearl millet (*Pennisetum tyhoideum* Rich.) grown in late summer. Jpn. J. Trop. Agr. (submitted).
8. Totok Agung Dwi Haryanto, N. D. Can and Tomohiko Yoshida 1998. Response of pearl millet in the different photoperiod. Bull. Inst. Trop Agr. Kyushu Univ. (submitted).

9.Totok Agung Dwi flaryanto, N. D. Can and T. Yoshida 1998. Crop propagation through immature inflorescence culture in pearl millet (Pennisetum tyhoideum Rich.). Plant Prod. Sci. (submitted).

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General Summary

Several studies were carried out to improve pearl millet population for higher grain yield. Pearl millet had high variability for several agronomic characters. A fairly large genetic gains were obtained and the heritability values were estimated for some agronomic characters. The phenotypic correlations and genetic correlations between grain yield and yield components were also calculated. In addition, the effective indirect selection through yield components to improve grain yield was developed.

Germination declined at low temperature. But, pearl millet was able to recover the growth and grain yield after low temperature stress in germination stage. Genotype x environmental interaction for selected genotypes was estimated. High yielding genotypes should be selected in separate environments.

Early spring planting inhibited the early growth stage but not the late growth stage of genotypes. It was confirmed that pearl millet was the facultative short-day crop and the crop was considered as an early spring and fall season sowing grain crop.

Procedure of plant regeneration from immature inflorescence culture was developed. The procedure enabled rapid crop propagation of genetically identical materials.

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Summary

1. Performance of a pearl millet population was evaluated and the interrelationship among agronomic characters was statistically determined. Population had wide variability for the characters. There were significant phenotypic correlation and genetic correlations between pairs of characters. Compensatory effects between several pairs of the characters shown by the negative correlations of productive tillers to panicle length and panicle weight were found. Counterbalance phenomena were found in interrelationship among characters. Panicle weight, number of productive panicles and grain weight per panicle, ranked in that order, were characters significantly correlated and had high direct effect to grain yield. Therefore, selection for high grain yield genotypes indirectly through those characters is possible.

2. Populations selected for high value of grain yield, grain weight per panicle, panicle weight and number of productive panicles showed higher values of the selected characters than the original population. A fairly large genetic gains were obtained and heritability values were estimated as 0.74, 0.84, 0.65, and 0.50 for grain yield, grain weight per panicle, panicle weight and number of productive panicles, respectively. Genetic correlations of the grain yield to grain weight per panicle, panicle weight and number of productive panicles were 1.00, 0.89 and 0.75, respectively. Indirect selection through yield components improved grain yield. Accordingly, selection through yield components may be effective for improving grain

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yield.

3. Selection for yield and yield components improved each component by $73 \cdot 187$ %. Selection for grain weight per panicle and panicle weight increased grain yield by 243 and 158 %, respectively. Grain yield was between 371 and 590 g m⁻².

4. Recurrent selection improved grain yield and yield components. Genetic gain for yield and genetic correlations among yield components were calculated. Heritability of yield characters was estimated. Direct and indirect selection effects for increasing grain yield were compared. Effective indirect selection method through yield components to improve grain yield was developed.

5, Germination response patterns of two populations on the different levels of temperature were studied to select plants germinated at a low temperature and the selected populations were field-evaluated. Germination declined at low temperature. No different patterns were observed in the germination between populations as temperature was varied, and the linear patterns were obtained. Population selected at 15 °C and original population, however, showed no significant difference in grain yield, although the interaction with plant spacing wag detected. Pearl millet may have an ability to recover the growth after low temperature stress in germination stage, therefore, selection of genotypes adapted for early spring planting may be possible. 6. Selection was applied in tall and short statured populations for studying genetic gain and heritability of seedling characters at a low temperature and the correlations to yield components. The selection had a significant effect on germination characters. Selection for a long shoot or root at germination increased the percentage of germination, panicle length and panicle weight in the field. There were relationships between seedling characters and yield components. A fairly large genetic gain for seedling characters was obtained and the heritability values were 0.28 - 0.69 for shoot length and 0.37 - 0.76 for root length. Shoot and root length are heritable characters and may be used as selection criteria at low temperature. In addition, further selection for a longer shoot or root should be possible.

7. Differential responses of genotypes selected by low temperature germination in different environments on yield components were studied. Number of productive panicles, panicle weight and grain yield were different with plant spacing. Most of yield components were significantly different with planting seasons. Fall season sowing showed lower yield components value, and closer spacing increased grain yield. Genotype x spacing interaction for number of productive panicles and panicle weight, and genotype x season interaction for panicle weight and grain weight per panicle were identified. No genotype x environment interaction for panicle length and grain yield was observed. Panicle length was considered as a stable character. Pearl millet might be considered as an early spring and fall season sowing grain crop. High yielding genotypes should be selected in separate environments.

8. Early spring planting inhibited the early growth stage, but not the late growth stage. Significant growth response was mainly by the difference of planting date. Significant differences among genotypes for grain yield and yield components responses were observed. No genotype x planting date interaction was observed for growth, grain yield and yield components, except for leaf area. Genotypes selected for grain yield, number of productive panicles and panicle weight were relatively stable in different planting dates and might be considered to be adapted for early spring planting.

9. Responses to different photoperiod were studied using three and four week-old seedlings. Upper part dry weight, 50 % heading, grain filling period, harvest index, grain weight per panicle and grain yield per plant were sensitive to photoperiod. Sixteen hour days increased upper part dry weight by 191 %, prolonged 50 % heading and grain filling period each by 10 days. However, decreasing harvest index, grain weight per panicle and grain yield per plant by 78 %, 28 % and 37 %, respectively with 16 h days was observed. Except for 50 % heading, no effect of 8 h days on all characters was observed. Number of productive panicles, panicle length and panicle weight were relatively insensitive to photoperiod. Different seedling age affected the sensitivity for 50% heading, harvest index and grain weight per panicle. It was confirmed that pearl millet was the facultative short-day crop.

10 The procedure of plant regeneration from immature inflorescence was developed.

A high frequency of callus formation from immature inflorescence culture was obtained. The procedure enabled rapid crop propagation of genetically identical materials. Chromosome number as 2n=14 was confirmed in root tip cells originated from both grains germinated and pantlets regenerated.

I. INTRODUCTION

Pearl millet (*Pennisetum tyhoideum* Rich.) is the most productive grain and a principal food cereal in extremely dry or infertile soils of India and Africa (Martin et a1., 1976), the fourth most extensively cultivated cereal, alter rice, wheat, and sorghum in India (Burton, 1980), and tolerate drought, low soil fertility, and low pH (Anand Kumar and Andrews, 1993). It is also used as forage in Australia, Southern Africa, South America, and USA (Anand Kumar and Andrews, 1993; Poehlman, 1994; Burton and Wilson, 1995; Degenhart et al., 1995).

According to FAO (1997), total world hectarage is 36.5 million ha and produces in amount of 29.5 million ton per year. From total area, 19.1 million ha (52 %) is distributed in Africa with average 676 kg grain yield per ha; and 13.5 million ha (37 %) is in India with average 778 kg per ha. World average grain yield is 809 kg per ha. To resolve the low grain yield, breeding for high yielding cultivars is urgently necessary.

Breeding of pearl millet received very little attention because it was generally considered as a low income crop. Only in recent years the research to determine the potential of millet as a grain crop has received serious consideration (Poehlman, 1994). In addition, because of its exceptional ability to tolerate drought, grain production of the crop may in the near future extend into regions too arid for sorghum (Burton, 1983).

Anand Kumar and Andrews (1993), Martin et al. (1976) and Poehlman (1994)

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mentioned that pearl millet had a high yield potential and responded well to moisture and soil fertility. Anand Kumar and Andrews (1993) and Yoshida and Sumida (1996) reported that the crop showed potential as an early-maturing summer grain crop in temperate region. Furthermore, several improved pearl millet cultivars have been developed in West Africa without significant yield gains (Ouendeba et al., 1993, 1995; Rajat De and Gautam, 1987). Efforts to improve grain yield and production of pearl millet, therefore, should be enhanced.

The author, therefore, made several fundamental studies for planning a successful breeding program in the crop, which included; 1). To estimate genetic variability and the interrelations among agronomic characters in the source population. In addition, indirect selection through characters correlated with yield was also studied. 2). To estimate genotype x environment interaction to obtain the informations for breeding genotypes with stability or specific superiority. Genotypes selected for low temperature were used for this study. 3). To understand response of pearl millet to photoperiod. Knowledge of photoperiod sensitivities has enabled to select for increased adaptability to various latitudes. Genotypes with different seedling ages were used in this study. 4). To propagate pearl millet asexually. It enables to obtain genetically identical materials quickly, though it is usually difficult to maintain the genotype stability through grain propagation in open pollinated crops.

1. Indirect Selection through Yield Components and Its effect on Grain Yield

Information regarding with genetic variability and interrelationship among characters in relation to grain yield of pearl millet is one of the most important

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factors in planning a successful breeding program in the crop plant. It is because success in plant breeding is generally dependent on the genetic variability in the source population. A high level of variability in the population for the characters of interest is, consequently, required for effective selection (Fehr, 1987a). In addition, interrelationship among characters is a guidance in choosing the most important characters to select for higher grain yield.

The yield should not be considered as a single trait but rather a group of traits, composed of the many components and is the final result of a plant life cycle (Borojevic, 1990). Also, selection for a character may be possible to achieve more rapid progress under selection for correlated response than from selection for desired character itself (Falconer, 1981). Therefore, study on the performance and interrelationship among characters in pearl millet is important.

Yadav (1994) studied the genetic divergence of Indian and exotic origin pearl millet accessions. Ouendeba et al. (1995) measured the phenotypic correlations among thirteen characters in pearl millet. They showed that grain yield significantly correlated with spike length, spike circumference, leaf width, stem diameter, spike number, non productive tillers, plant height, spike yield, but not significantly correlated with days to flowering. Inheritance of vegetative growth index and related characters in pearl millet was reported (Lynch et al., 1995). Little studies, however, were conducted on variability and relationship among characters of pearl millet especially under late summer sowing condition.

Plant breeders commonly select plants through yield components that correlate to

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yield. Gravois and McNew (1993) reported that number of panicles was the single most important component of yield in rice. A significant effect of indirect selection was reported in soybean (Tinius et al., 1993), maize (Burgess and West, 1993), and barley (Van Oosterom and Ceccarelli, 1993). But, the indirect selection through yield components for grain yield of pearl millet is scarcely studied.

In pearl millet, population improvement procedures have recently been subjected as a breeding effort to exploit the crop potential. The population may be improved by recurrent selection procedures. The cross pollination of the crop makes it unnecessary to utilize male sterile genes for developing a random-mating population (Poehlman, 1994). The genetically superior plants are selected from a population and inter-mated to reconstitute an improved population in recurrent selection (Klein et al., 1993).

Recurrent selection in oat was an effective breeding procedure for improving test weight and grain yield without significant reduction in genetic variability (Rein et al., 1993). Recurrent selection in oat for stability of yield (Reysac et al., 1993) and kernel morphology (De Koeyer et al., 1993), for grain yield in maize (Burgess and West, 1993; Keeratinijakal and Lamkey, 1993) and for grain size in soybean (Tinius et al., 1993) was reported.

Although recurrent selection is proven to be effective for the improvement of quantitative characters in both self- and cross-pollinated crops (Reysack et al. 1993), it is necessary to evaluate the effectiveness for improving grain yield and yield components of pearl millet. Furthermore, comparison between grain yield response to direct and indirect selection was important. Efficiency of selection procedure can be evaluated as the amount of genetic improvement or genetic gain realized per cycle of selection. The concept of genetic gain is based on the change in the mean performance of a population that is realized with each cycle of selection (Fehr, 1987a). Furthermore, relative importance of genetic and non genetic factors of phenotype, which is referred to heritability, has a major impact on the genetic gain expected (Falconer, 1981). Estimation of heritability and genetic gain for grain yield and yield components of pearl millet may become an useful information in developing breeding programs of pearl millet.

2. Genotype x Environmental Interaction

As plant performance is influenced by genotype, environment and their interaction, the study regarding with genotype x environment interaction in pearl millet may become a valuable information. Every factor that is a part of the environment of a plant has the potential to cause differential performance on its growth. All of the variables encountered in producing a crop can be described collectively as the environment and changes in the relative performance of genotypes across different environments are referred to as genotype x environment interaction (Fehr, 1987a).

Current world crop production is limited largely by environmental stress. Environmental stress was the main factor responsible for the disparity between potential and actual yield (Blum, 1988). Temperature has often overriding importance for seedling growth, especially in chilling-sensitive species (Richner et al., 1996). Any temperature outside the optimum range is considered as non optimum and may be considered as a stress temperature (Blum, 1988). Low temperature at sowing delays both germination and plant emergence, lengthens the crop cycle and increases production costs by demanding greater irrigation time (Otubo et al., 1996). Low temperature becomes one of the main limiting factors for grain germination in the early spring planting. It also carries an effect on subsequent seedling growth and its field performance. An understanding of the low temperature germination and the genetic study of the germination characters at low temperature would facilitate cultivar development for early spring planting adaptation.

Yoshida and Sumida (1996) studied mass selection for early germination at low temperature of pearl millet and had estimated the heritability value. Bertin et al. (1996) screened rice varieties for chilling tolerance during germination and vegetative growth from 10 to 25 °C. Redona and Mackill (1996) studied genetic variation for seedling vigor characters in rice at 18 and 25 °C. Heritability value and genetic gain for seedling root length and coleoptyle length in pearl millet was estimated (M'Ragwa et al., 1995).

Pearl millet had potential as an early-maturing summer grain crop in temperate region (Anand Kumar and Andrews, 1993). Study on grain yield and its components in relation to both spring and fall sowing is important.

As genotype response might be influenced by changing plant spacing and planting date, more advantages might be achieved when the spacing and/or planting date are considered in the genotype x environment interaction study.

Genotype x season or spacing interactions were studied in rice, maize, sorghum,

soybean and navy bean (Board et al., 1996; Cox, 1996; Gravois and Helms, 1992; Mahajan and nehra, 1992; M'Khaitir and Vanderlip, 1992; Oosato et al., 1996; Prasad and Singh, 1990; Redden et al., 1997; Wells, 1993).

In pearl millet, studies on heterosis and/or stability in different spacing and seasons also was reported (Dave and Joshi, 1995; M,Khaitir and Vanderlip, 1992; Pethani, 1993; Pethani and Dave, 1992). However, little information is available on the influence of genotypes selected for low temperature germination x season interaction on grain yield and its components in pearl millet which is grown in different planting density.

3. Response to Low Temperature Stress and Photoperiod Sensitivity

As different planting dates might result in different photoperiod and temperature regimes, which affect both growth and yield or yield components, the potential of genotypes could be affected by their responses to planting date. An understanding of the response of genotypes to different planting date might facilitate developing pearl millet adapting to early spring sowing. Furthermore, knowledge of photoperiod sensitivities has enabled breeders to select for increased adaptability of cultivars to various latitudes (Fehr, 1987a).

Many researches were conducted to study the photoperiod sensitivity of crops. Studies in. wheat (Miglietta, 1989; Slafer and Rawson, 1995, 1996; Slafer et al., 1995; Brooking et al., 1995; Hotsonyame and Hunt, 1997), sorghum (Muchow and Carberry, 1990), triticale (Ewert, 1996), common bean (White and Laing, 1989), peanut (Bagnall and King, 1991a,b), groundnut (Linnemarm, 1991; Linnemann et al., 1995), pigeonpea (Onanga et al., 1995) and *brassica* spp. (Nanda et al., 1996) using various characters were reported.

Photoperiod sensitivity in pearl millet is a well recognized character (Anand Kumar and Andrews, 1993). Most of pearl millet landraces and lines are photoperiod sensitive (Burton, 1981), capable for flowering at all photoperiods though much earlier with short days (Begg and Burton, 1971) and possible to be developed into high-yielding photoperiods insensitive genotypes (Bhardwaj and Webster, 1971; Burton, 1981). However, study on photoperiod sensitivity for growth characters and yield components in pearl millet which differs in their seedling age of transplanting date was scarce.

4. Crop Propagation through Immature Inflorecence Culture

In open pollinated crops, it is difficult to maintain the genotype stability through grain propagation. In vitro culture is aimed primarily to a rapid propagation of superior genotypes which are identical to the source material (Borojevic, 1990). The tissue and cell culture had been developed since Haberlandt (1902 in Borojevic, 1990) emphasized the totipotency of somatic cells in plants and pointed out the possibility of producing plants by means of tissue culture. These techniques are a basic implement for various gene manipulations (Borojevic, 1990). In vitro crop propagation enables to develop a new commercial cultivar more quickly (Pierik, 1987) and more success has so far been achieved with annual plants than with perennial plants as well as with horticultural plants and grasses than with legumes and forest trees (Borojevic, 1990).

In vitro crop propagation, therefore, may be useful to propagate selected genetically

identical genotypes rapidly.

Plant regeneration from cultured immature inflorescence (Takahata, 1988); and from cotyledon fragments (Srejovic and Nescovic, 1981) in buckwheat were reported. Bajaj and Gupta (1992) studied in vitro regeneration and somaclonal variation for salt tolerance using young unopened inflorescence of Indian pearl millet cultivar. Pius et al. (1993) studied ethylene inhibitors and cefotaxime for enhancing plant regeneration in pearl millet. Therefore, it is important to develop a procedure for plant regeneration from immature inflorescence culture which may be applied in the selected genotypes of pearl millet.

The study in this thesis are itemized as follows:

Evaluation of performance and variability of several agronomic characters and their interrelationships in relation to grain yield.

Indirect effect of selection through yield components to grain yield

■ Recurrent selection on grain yield and estimating genetic gain, heritability and genetic correlations of yield components in relation to grain yield

■ Germination response patterns on different levels of temperature and the selection of seedlings germinating at a low temperature

■ Selection for seedling characters at low temperature, and estimating the heritability and genetic gain of those characters

■ Genotype response to spring and fall season sowing, effect of plant spacing, and their interaction on yield components

Growth and grain yield response to different planting date in relation to grain yield of genotypes adapting to early spring sowing

■ Response of genotype to photoperiod and the influence of seedling age on the sensitivity

Development of plant regeneration procedure through immature innorescence culture for propagation of selected genotypes

From these studies, the followings could be clarified: 1). Variability and correlation among several agronomic characters, efficiency of selection using the correlated characters and of recurrent selection for high grain yield, 2). Genetic gain and heritability of seedlig characters and yield components, 3). Genotype **x** environmental interactions, 4). Genotypes response to environmental conditions including low temperature stress in germination, sowing season, plant spacing, planting date and photoperiod and 5). Plant regeneration procedure through immature inflorescence culture.

II. INDIRECT SELECTION THROUGH YIELD COMPONENTS AND ITS EFFECT ON GRAIN YIELD

1. Performance and Interrelationship among Several Agronomic Characters

Introduction

Many studies were carried out in an attempt to study the performance and interrelationship among characters in pearl millet and other crop plants. Variability and intercharacters associations in several crops were reported (Dedaniya and Pethani, 1994; Mogali and Virupakshappa, 1994; Rath et al., 1994; Sena et al., 1994). In pearl millet, Yadav (1994) studied the genetic divergence, Diz et al. (1995) worked on the defoliation effects and grain yield components, Ouendeba et al. (1995) researched the diversity among landrace populations, Lynch et al. (1995) studied about vegetative growth index and related traits inheritance and Degenhart et al. (1995) investigated the forage yield in pearl millet mutants. Yoshida and Sumida (1996) tried mass selection for early heading to grow this crop in late summer after rice harvesting. However, the information about performance and interrelationship among characters is not enough for the crop grown in late summer in Japan.

Objectives of the research are: 1) to evaluate performance of several characters of pearl millet population grown in late summer, 2) to study the correlations and compensatory effects between several characters and grain yield, 3) to determine the direct and indirect effects of several characters in relation to grain yield, and 4) to determine the most important character(s) to grain yield in pearl millet.

Materials and methods

A heterozygous population of three hundred and ten plants was grown in Experimental Farm of Faculty of Agriculture, Kyushu University, Fukuoka during middle of August 1995 to end of November in 1995. The material was obtained from an early maturing and short statured "ICMV89074" of ICRISAT (India) and the number of seeds was increased by open pollination in several seasons including May and August sowing. On 10 August 1995, seeds were sown in four rows and thinned after 2 weeks of emergence to 15 x 60 cm between and within rows. Amount of 0.8 g N, 0.8 g P_2O_2 and 0.8 g K_2O $m^{\cdot 2}$ each of were fertilized at the date of planting. All of plants were subjected to total of ten characters observation. Plant height (cm), total number of tillers, number of productive tillers, total number of panicles, and number of productive panicles per plant were measured before harvesting. Panicle length (cm), panicle weight (g), grain weight per panicle (g), 100-grain weight (g), and grain yield per plant were evaluated after harvesting. Germination test was conducted using seeds of the highest 10% and the lowest 10 % plants of population for each character evaluated.

Each of data set was subjected to Lilifors's normality distribution assessing (Conover, 1980). Analysis for coefficient of correlation and path coefficient



Fig. 1. Diagram of path coefficient analysis of nine agronomic characters (x1-x9) to the grain yield (x10) of pearl millet. Straight lines show direct effects and curve lines show indirect effect for each character to grain yield. Where: x1-x10 and R are plant height (cm), total number of tillers, number of productive tillers, total number of panicles, number of productive panicles, panicle length (cm), panicle weight (g), grain weight per panicle (g), 100-grain weight (g), grain yield per plant (g), and residual effects, respectively.

was referred to Steel and Torrie (1980) and Li (1975). Causal relationship between several characters and yield of pearl millet in a path diagram is shown in Fig. 1. Minimum, mean, maximum, variance, coefficient of variation, and standard error values were counted.

Results

(1) Population Performances

Population performance including minimum, mean, maximum, variance, coefficient of variation, and standard error values for each of characters are shown in Table 1. The frequency distributions are shown in Fig. 2. In general, the population widely varied for the characters measured. The wide variability was expressed by high value of coefficient variation, higher than 20 %, for most of characters. The coefficient of variation value was between 22 and 100.

Fig. 2 showed that plant height, total number of tillers, panicle length, panicle weight, and 100-grain weight per plant were characters normally distributed.

Mean performance of the highest 10 % and lowest 10 % plants of population for all characters and the mean of each % germination are shown in Table 2. It shows that % germination of the highest 10 % population was between 90 and 100 %, and averaged 95.2 %. The lowest 10 % population, however, was between 24 and 100 %, and averaged 67.2 %. The highest 10 % population,

Characters	Minimum	Maximum	Mean	Variance	Coeff. of	Standard
	value	value	value		variation	(%) error
		1.0.5	2.0		2.2	1.0.4
Plant height (cm)	30	165	89	559	26	1.34
Total number of tillers	1.00	7.00	3.20	1.67	40	0.07
Number of prod. tillers	1.00	5.00	1.40	0.59	55	0.04
Total number of panicles	1.00	9.00	1.77	1.67	73	0.07
Number of prod. panicles	1.00	5.00	1.39	0.62	56	0.07
Panicle length (cm)	9.87	31.00	18.43	16.32	22	0.23
Panicle weight (g)	1.10	31.05	9.62	35.33	62	0.34
Grain weight per panicle (g)	0.01	19.36	4.73	16.24	85	0.23
100-grain weight (g)	0.12	1.51	0.57	0.07	45	0.02
Grain yield per plant (g)	0.01	47.21	6.86	53.65	100	0.42

Table 1. Variation of several characters among plants within a pearl millet population.



Fig.2 Frequency distribution of several characters for plants in pearl millet populations.

therefore, performed 28.0 % germination higher than the lowest 10 % population for all characters.

(2) Interrelationship among Characters

Coefficients of correlation among characters are represented in Table 3. Plant height had significant correlations to all characters except for number of productive tillers, number of productive panicles, and panicle length per plant. Total number of tillers per plant had significant correlations to all of characters except for panicle length.

Number of productive panicles had significant correlations to all characters except for plant height, panicle length, panicle weight, and grain weight per panicle. Panicle length had significant correlations to total number of panicles, panicle weight, and grain weight per panicle. Panicle weight had significant correlations to all characters except for number of productive panicles and number of productive tillers. Grain weight per panicle had significant correlation to all characters except for number of productive tillers, total number of panicles, and number of productive panicles per plant. Grain yield and 100-grain weight had significant correlations to all characters except for panicle length.

The highest value of coefficient correlation (0.802) was between total number of panicles and number of productive panicles, followed by the values between number of productive tillers and number of productive panicles (0.778),

Characters	The highest 10%	Germination mean(%)	The lowest 10%	Germination mean (%)
Plant height (cm)	132.6	100	51.2	100
Total number of tillers	5.3	93	1.0	76
Number of prod. tillers	3.3	93	1.0	76
Total number of panicles	4.9	90	1.0	76
Number of prod. panicles	3.4	96	1.0	76
Panicle length (cm)	26.3	96	12.1	44
Panicle weight (g)	22.1	99	2.3	95
Grain weight per panicle (g)	13.2	100	0.2	62
100-grain weight (g)	1.1	92	0.2	24
Grain yield per plant (g)	24.1	94	0.2	52

Table 2. Mean performance of the highest 10 % and the lowest 10 % plants of population and the % germination.

and between number of productive tillers and total number of tillers (0.732). The most correlated character to the grain yield was the panicle weight, followed by number of productive panicles, number of productive tillers, total number of panicles, and grain weight per panicle. Ouendeba et al. (1995) also reported that number of productive tillers per plant showed the strongest association to the grain yield of pearl millet.

Negative correlations were found only between number of productive tillers and panicle length, and between number of productive tillers and panicle weight, which was confirmed by Ouendeba et al. (1995).

Results of path coefficient analysis for each character to the grain yield are shown in Table 4. Sum of the direct effects (path coefficient) of each character, underlined, and indirect effects through other characters results in the correlation between the character and grain yield. It seemed that plant height, total number of tillers, and number of productive tillers per plant were the characters which had negatively direct effect on the grain yield. Other characters had positive direct effect on the grain yield. Number of productive panicles, grain weight per panicle and panicle weight, ranked in this order, were characters having highest direct effect on grain yield.

Discussions

The high level of variability is an important factor in the crop improvement program. It determines; the selection effectiveness and the magnitude of

Characters	XI	X2	X3	X 4	X5	X6	X7	X8	X9	X10
X1	1									
X2 0.	147*	1								
X3 0.	082	0.452**	1							
X4 0.2	207**	0.452**	0.732^{**}	* 1						
X5 0.	090	0.416**	0.778*	* 0.802*	* 1					
X6 0.	044	0.058	-0.043	0.192**	* 0.094	1				
X7 0.3	365**	0.270**-	0.061	0.116*	0.058	0.409**	1			
X8 0.	324**	0.162**	0.067	0.095	0.026	0.161**	* 0.655**	* 1		
X9 0	449**	0.283**	0.136*	0.313**	0.193**	0.017	0.236**	0.259**	1	
X10 0.3	312**	0.373**	0.457**	*0.409**	0.559**	0.095	0.609**	0.397**	0.321**	1

Table 3. Coefficients of correlation among several characters of pearl millet population.

*, **; significant at 5 and 1 % level, respectively.

- X1 ; plant height (cm). X6 ; panicle length (cm).
- X2, total number of tillers. X7; panicle weight (g).
- X3; number of productive tillers. X8; grain weight per panicle(g).
- X4 ; total number of panicles. X9 ; 100-grain weight (g).

X5; number of productive panicles. X10; grain yield per plant (g).

Table 4. Path coefficients between Several agronomic characters; and grain yield of pearl millet population (for X1-X9, see Table 3).

	X 1	X2	X3	X4	X5	X6	X7	X8	3 X9) r
V1	0.000	0.000	0.000	0.001	0 500	0.000	0.000	0.001		0.919
λI	-0.026	-0.009	-0.008	-0.021	0.583	0.002	0.038	0.231	0.005	0.312
X2	-0.003	-0.046	-0.038	0.031	0.256	0.005	0.059	0.089	0.003	0.373
X3	-0.001	-0.022	<u>-0.071</u>	0.033	0.445	0.002	0.002	0.068	-0.001	0.457
X4	-0.034	-0.021	-0.053	0.003	0.435	-0.006	0.011	0.008	0.002	0.409
X5	-0.002	-0.022	-0.058	0.023	0.563	-0.003	0.030	0.026	0.001	0.559
X6	-0.001	-0.009	-0.002	0.002	-0.035	0.045	-0.125	0.198	3 0.001	0.095
X7	-0.011	-0.010	-0.003	0.003	-0.018	0.021	0.153	0.474	0.001	0.609
X8	-0.009	-0.002	-0.001	-0.005	-0.003	0.013	-0.152	0.458	0.005	0.397
X9	-0.014	-0.008	-0.011	0.015	0.107	0.001	0.035	0.151	0.011	0.321

Direct effects are in main diagonal (underlined) for each character and indirect effects via the other characters to grain yield are in the same row.

selection response which is desirable. In this study, as several characters showed high values the coefficient of variation, the high variability was observed for these characters.

The importance of assessing the population mean value and maximum value is that the effective selection in a population results in a change in the population mean value for character evaluated. The magnitude of distance between mean and maximum values also may indicate the possibility to improve the characters by selection.

Negative correlations, as shown in Table 3, indicate the compensatory effects between characters. It means that the increasing of the productive number of tillers may be followed by decreasing of panicle length and panicle weight. In contrary, the increasing of panicle length and/or panicle weight may result in the decrease in number of productive tillers. Positive correlation in many of characters relationship interprets the similarity of direction of the trend association. These results were confirmed by the positive correlations of the primary panicles per plant, grain weight per panicle, and 100-grain weight to the grain yield of pearl millet by Diz et al. (1995).

Although direct effects of the plant height (-0.026), total number of tillers (-0.046), and number of productive tillers (-0.071) on the grain yield were negative, they were counterbalanced by positive high values of indirect effects through grain weight per panicle, panicle weight and number of productive panicles; as 0.583, 0.256, and 0.445, respectively, resulting in their positive correlation to the grain yield.

Relatively high value of direct effects of grain weight per panicle, panicle weight,

and number of productive panicles on the grain yield as 0.548, 0.153, and 0.563, respectively and significant correlation to the grain yield (r= 0.397, r=0.609, and r=0.559, respectively) showed that these characters were the most influential agronomic characters to the grain yield. Therefore, indirect selection for high grain yield genotype through these characters might be possible.

2. Effects of Selection through Yield Components on Grain Yield

Introduction

Plant breeders commonly select plants for yield components that indirectly increase yield. Gravois and McNew (1993) reported that the number of panicles per unit area was the single most important component of yield in rice. A significant effect of indirect selection also was reported in soybean (Tinius et al., 1993), maize (Burgess and West, 1993), and barley (Van Oosterom and Ceccarelli, 1993). Furthermore, the effectiveness of repeated selection for improvement of quantitative traits was reported in both self- and cross pollinated crops (Reysack et al., 1993), kernel morphology (De Koeyer et al., 1993), stability of yield (Reysack et al., 1993) and grain yield in oat (Klein et al., 1993), grain size in soybean (Tinius et al., 1993), grain yield stability in sorghum (Chisi et al., 1996), and grain yield in maize (Burgess and West, 1993: Keeratinijakal and Lamkey, 1993). However, few studies were made on the indirect selection through yield components for pearl millet grain yield.

In this section, the effect of selection through each yield component on the improvement of grain yield of a short statured pearl millet population was examined.
Heritability and genetic gain of the characters and their genetic correlations were also estimated.

Materials and Methods

(1) So population

Seeds of an open pollinated pearl millet were sown in a field on August 1995 to produce the So population in the experimental field. The material was obtained from an early maturing and short statured "ICMV89074" of ICRISAT (India). The plants were planted at 15 and 60 cm intervals within and between rows, respectively, and 0.8 g N, 0.8 g P_2O_5 , and 0.8 g K₂O per m² were applied in four rows with 75 plants per row and selfed. Grain yield per plant and grain weight per panicle, panicle weight and number of productive panicles per plant were measured for all plants in the So population. Plants were selected for the highest 10 % and lowest 10 % yield and each yield component and the selected plants were harvested separately.

(2) Polycrossing of selected plants

Seeds from 9 genotypes, namely selected for high and low grain yield, grain weight, panicle weight, and number of productive panicles, and the parent, were sown in paper pots, 6x5x5 cm, filled with fertile soil. Three weeks later, on May 1996, seedlings were transferred to plastic pots in a greenhouse. One pot was filled with about 4 kg sifted soil, 0.8 g N, 0.8 g P₂O₅, and 0.8 g K₂O. Twelve plants growing in 6 pots were used per group.

Panicles were bagged before heading, polycrossed among individuals manually within a group and harvested separately on August 1996 to obtain the seeds of S1 population.

(3) Evaluation of S1 population

Seeds from 9 genotypes were sown in paper pots, grown for 2 weeks and then transplanted to a field on 18 August 1996. A randomized complete block design with 2 replications was applied. One plot consisted of two rows with 10 plants each. Seedlings were planted at 10 and 50 cm intervals within and between rows, respectively, and 0.8 g N, 0.8 g P_2O_5 , and 0.8 g K₂O were applied per m². Five plants per plot were sampled for evaluation of grain yield and yield components. Plants were harvested on 8 November 1996.

(4) Statistical analysis

Data obtained in the S1 population were subjected to analysis of variance continued by protected LSD test (Steel and Torrie, 1980) using IRRISTAT 3/93 (IRRI, 1993). Heritability (h²) was estimated using the following formula (Falconer, 1981; Fehr, 1987a):

$$h^{2} = \frac{x_{1} \text{ high } \cdot x_{1} \text{ low}}{x_{0} \text{ high } \cdot x_{0} \text{ low}}$$

where, x_0 high and x_0 low are mean values of each character of individuals selected for the original population for high and low characters, respectively, and x_1 high and x_1 low are those of the genotype derived from mating the selected individuals for high and low characters, respectively.

The genetic gain was calculated as x_1 sel - x_1 op.

where, xisel and xiop are the mean values of the genotype selected for the character

and that of original population, respectively.

Genetic correlations were calculated as follows (Falconer 1981; Fehr, 1987a):

rA=
$$\frac{Cr_x i_x h_x}{R_x i_y h_y}$$

where, Cr_x and R_x are amount of improvement in primary character obtained by indirect selection for secondary character (yield components) and by direct selection for primary character (yield), i_x and i_y are selection intensity for primary and secondary characters (as 1.75 for 10% selection of population), and h_x and h_y are square root of heritability for primary and secondary characters, respectively.

The % improvement of yield and each yield component was calculated as follows:

Percent of improving =
$$\frac{x_1 \operatorname{sel} - x_1 \operatorname{op}}{X_1 \operatorname{op}}$$
 x 100

Results

Table 5 shows the analysis of variance for several characters after one selection cycle. A significant effect of selection was observed on almost all characters, that is, both upward and downward selections were effective for each character. Genotypes differed in panicle weight, panicle length, grain weight and grain yield.

Table 6 shows the mean values of genotypes selected for grain yield and yield components.

(1) Population performance

No significant difference in plant height was observed among the genotypes selected for high and low grain yield and each yield component. This suggests that selection for yield and each yield components had no deteriorating effect to lodging.

Panicle length was higher in the genotypes selected for high yield and each yield component than in those selected for low performance or original population. This means that the selection for these characters was effective even on the unselected character, panicle length.

The average number of productive panicles in the So population selected for high and low number of productive panicles was 3.4 and 1.0, respectively (Table 2). However, no significant difference was detected among the S1 genotypes

Source	df	Plant height	Panicle length	No.of prod.	Panicle	Grain weight	Grain yield
		(cm)	(cm)	panicles	weight(g)	per panicle(g)	per plant(g)
	0	910	100**	0.20	7 9.0**	0.0.1**	170**
Genotype	0	218	10.8	0.39	75.0	33.1	170***
Residuals	8	103	1.4	0.17	1.6	1.4	27

Table 5. Mean squares by ANOVA for genotypes after one selection cycle.

*, **; significant at 5 and 1 % level, respectively.

Genotype	Plant height (cm)	Panicle length (cm)	No.of prod. panicles	Panicle weight (g)	Grain weight per panicle (g)	Grain yield per plant (g)
Selected for high:						
grain yield per plant	105 a	20.4a	2.2a	18.0b	10.7b	24.7a
grain weight per panicle	108 a	22.9a	1.9a	22.4a	15.4a	29.5a
panicle weight	108 a	21.0a	1.7a	20.7ab	b 12.9ab	22.2a
no.of prod. panicles	95a	17.1b	2.5a	14.1c	7.5c	18.5 b
Selected for low:						
grain yield per plant	89a	16.1bc	1.4a	7.8d	5.0cd	7.0bc
grain weight per panicle	86a	14.2c	1.4a	6.8d	4.5d	6.2c
panicle weight	90a	15.3bc	e 1.2a	7.8d	4.6d	5.5c
no.of prod. panicles	78a	16.7bc	1.3a	8.2d	5.1d	6.7bc
Original population	93a	17.4b	1.5a	11.9	c 5.9cd	8.6bc
c.v. (a)	10.7	6.7	24.5	9.8	14.7	36.1

Table 6. Mean values for grain yield and each yield component of genotypes after one selection cycle.

Means followed by a common letter within a column are not significantly different at 5% level according to ANOVA protected LSD test.

selected for high and low performance or original population in the number of productive panicles probably due to a sampling error.

Panicle weight was higher in the genotypes selected for high grain yield and each yield component than in those selected for low performance or the original population. Panicle weight increased by 73 % (Data not shown in Table) and decreased by 35% after selection for high and low yield, respectively.

Grain weight per panicle was higher in the genotypes selected for high yield and each yield component than in those selected for low performance or original population. Grain weight was increased by 159 % after selection for high performance.

Grain yield per plant was higher in genotypes selected for high yield and each yield component than in those selected for low performance or original population, except for productive panicles. The mean values were not significantly different among genotype selected for yield and each yield component. No significant difference was observed in grain yield between the genotypes selected for low performance and original population. Direct selection for high yield increased the grain yield by 186 %.

(2) Selection for yield component effects

Table 6 shows the effects of indirect selection through each yield component on grain yield. The grain yield of genotypes selected for high yield components was significantly higher than that of the genotypes selected for low grain

Table 7. Realized genetic gain (a) and heritability (h^2) values for grain yield and yield components estimated alter one selection cycle.

Characters	$G(x_1 sel - x_1 op)$	h^2
Grain yield per plant	12.8	0.74
Grain weight per panicle	7.1	0.84
Panicle weight	7.9	0.65
No. of productive panicles	1.0	0.50

 x_1 sel and x_1 op; mean of selected genotype and original population, respectively.

Table 8. Genetic correlations between grain yield and yield components.

Grain yield per plant vs.	Genetic correlation	
Grain weight per panicle	1.00	
Panicle weight	0.89	
No. of prod. panicles	0.75	

weight, low panicle weight or low number of productive panicles and original population. Selection for high grain weight per panicle showed the highest effect on grain yield (243 %), followed by selection for high panicle weight (157 %) and number of productive panicles (115 %).

(3) Estimation of heritability

Table 7 shows the genetic gain by selection intensity of 10 % for yield and each yield component. The genetic gain calculated from the "high selection-population mean" was 12.80, 7.10, 7.86, and 1.00 for grain yield, grain weight, panicle weight and number of productive panicles, respectively.

Heritability values for grain yield, grain weight, panicle weight, and number of productive panicles were 0.74, 0.84, 0.65, and 0.50, respectively (Table 7).

(4) Genetic correlation

Table 8 shows the genetic correlations between grain yield and each yield component. The values were 1.00, 0.89 and 0.75 for grain weight per panicle, panicle weight and number of productive panicles, revealing genetically close relationships between grain yield and these characters.

Discussion

As the genotype selected for grain yield showed higher grain yield than original population, the improving of grain yield was verified. The grain yield was between 371 and 590 g m⁻² The increase in grain yield of pearl millet indicated that the selection procedure practiced in this study was effective for grain yield. Improvement of grain yield by 26.8 % and 55.3% on row and hill plots, respectively after five

selection cycles has also been reported in oat (De Koeyer et al., 1993). A 44% yield increase after four cycles in the random-mated maize population (Burgess and West, 1993), gain from 17.7 to 44.0 % based on hill plot after four selection cycles for oat grain yield also was obtained (Reysack et al., 1993).

Selection through yield components increased grain yield as 115 - 243 %. Thus, indirect selection through grain weight per panicle, panicle weight and number of productive panicles clearly improved grain yield. In addition, these also indicated that the indirect selection practiced in this study was effective.

Indirect selection for grain size was reported effective on grain composition in soybean (Tinius et al., 1993), for ear height on yield in maize (Burgess and West, 1993), for plant ideotype and heading date on yield of barley under stress (Van Oosterom and Ceccarelli, 1993).

A fairly large values of heritability as 0.50 - 0.84 was estimated for yield components. These results suggest that further selection for these characters is effective to improve the yield.

Falconer (1981) mentioned that indirect selection was effective if the secondary characters had higher heritability and were closely correlated to the primer character. Hallauer et al. (1988) reviewed many studies on the effectiveness of direct and indirect selections for grain yield in corn. Improvement of yield through yield components was also reported in rice (Gravois and McNew, 1993) and in wheat (Van Sanford and Utomo, 1995).

The relatively high genetic correlation between each yield component and grain

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yield suggests that selection for these characters is effective to improve grain yield.

In conclusion, selection for yield and each yield component improved each characters by 73 to 187 %. Indirect selection through yield component as practiced in this study clearly increased grain yield. Considering the high heritability and high genetic correlation to grain yield, grain weight per panicle, panicle weight and number of productive panicles are considered to be useful as indirect selection criteria for high grain yield.

3. Recurrent Selection for High Gran Yield, Genetic Gain and Genetic

Correlations among Yield Components

Introduction

The basic objectives of any recurrent selection system are: 1 to improve breeding populations in a cyclic manner by increasing the frequencies of favorable genes and gene combinations and 2 to maintain adequate genetic variability for further selection and improvement by intermating a sufficient number of superior genotypes in each cycle of selection (Pandey and Gardner, 1992). Increased frequency of favorable genes is advantageous for either population per gel performance or for inbreeding to produce improved homozygous lines (Dudley, 1997). Recurrent selection for several crops was reported (De Koeyer et al., 1993; Ghorpade and Metta, 1993; Klein et al., 1993; Keeratinijakal and Lamkey, 1993; May and Van Sanford, 1992; Reysack et al., 1993; Tinius et al., 1993) . In addition, Ghorpade and Metta (1993) reported the heritability values for grain yield in pearl millet as 0.31, 0.53 and 0.55 for full-sib, half-sib and S1 families, respectively.

Even recurrent selection had become a useful procedure in many crops improvement, a little information was available for the effectiveness of the direct or indirect through yield components to improve pearl millet grain yield. Indirect selection through yield components might reduce genotype x environment interaction for grain yield, which often hampers selection gain. Indirect selection in barley (Van Oosterom and Ceccarelli, 1993), maize (Burgess and West, 1993), soybean (Tinius et al, 1993) were reported.

Objectives of this section were 1 to study effectiveness of recurrent selection procedure for improving several selected and non selected characters, 2 to estimate realized genetic gain and heritability for grain yield and yield components and 3 to compare the direct selection with indirect selection through yield components in relation to improve grain yield sown in late summer, which might contribute to the farmer since no grain crops are usually grown after harvesting early-season rice (Yoshida, 1995).

Materials and Methods

Two cycles of recurrent selection were carried out on a short statured pearl millet population originated from "ICMV89074" genotype from ICRISAT, India.

S0 generation was developed in fall season of 1995. All plants were self-pollinated and characters as grain yield per plant, grain weight per panicle, number of productive panicles; and panicle weight were observed. The plants with 10% high and 10% low for those characters were selected, which resulted a creating 8 genotypes. Seeds of selected plants for each character were grown separately at later spring season and polycrossed among plants within each group. Seeds of polycrossed plants were sown separately as S1 generation at fall of 1996.

Same procedure was conducted to prepare S2 Seeds. The S2 Seeds of 9 genotypes including original were sown on 6 August, transplanted to the field on 28 August, and harvested on 18 November 1997. Selected characters as number of productive panicles, panicle weight, grain weight per panicle and grain yield per plant, and non selected characters as plant height, upper part dry weight, harvest index and panicle length were observed. The data were analyzed according to analysis of variance protected by LSD test using IRRISTAT 3/93 GRRI,1993). Heritability values were estimated from S1 to S2 populations. Genetic gains per cycle were calculated as the difference between mean values of selected genotypes and original population in S2 divided by two. Genetic correlation was calculated from the ratio between amount of improvement for a character obtained by indirect selection for a correlated character and obtained by direct selection for a character in S2. All of these were calculated according to Falconer (1981) and Fehr (1987a).

Results

Analysis of variance was presented in Tables 9 and 10 for selected and non selected characters, respectively. The mean values of genotypes for characters observed were shown in Tables 11 and 12.

Genotypes significantly differed for all characters, except plant height. Genotypes selected for high grain yield, grain weight, number of productive panicles and panicle weight showed higher mean values than both of original population and genotypes selected for low (Table 11 and Fig. 3). The higher mean values were also observed in genotypes selected for high than that of original population for non selected characters as upper part dry weight, harvest index, and panicle length (Table 12 and Fig. 3).

Source	df	No. of prod.	Panicle weight	Grain weight per	Grain yield
		panicles	(g)	panicle(g)	per plant(g)
Genotype	8	0.32*	86.7**	14.9**	104.4**
Residuals	9	0.13	7.5	0.6	24.2

Table 9. Mean squares by ANOVA for selected characters of genotypes after two recurrent Selection cycles.

*,**,. significant at 5 and 1% level, respectively.

Table 10. Mean squares by ANOVA for non selected characters of genotypes after two recurrent selection cycles.

Source	df	plant height (cm)	Upper part dry weight per plant(g)	Harvest index (%)	Panicle length (cm)
Genotype	8	61.9	145.9*	779*	17.0**
Residuals	9	107.5	43.2	289	2.6

*,** ; significant at 5 and 1% level, respectively.

Realized genetic gain and heritability values were shown in Table 13. Realized genetic gain for yield and its components varied from 0.6 to 6.1. Heritability values were estimated as 0.90, 0.47, 0.47, and 0.67 for grain yield, grain weight, number of productive panicles and panicle weight, respectively (Table 13).

Genetic correlations among yield and its component were presented in Table 14. The values varied from 0.51 to 1.00. Genetic correlation of grain weight, number of productive panicles and panicle weight to grain yield was 1.00, 1.00 and 0.73, respectively.

Table 15 presented the direct and indirect selection effects. Selection for grain yield, grain weight, number of productive panicles and panicle weight increased each character by 101, 85, 79 and 37 %, respectively. Increasing of grain yield each by 88, 74, and 19 % following to selection through grain weight, panicle weight and number of productive panicles, respectively was also observed. Percentage increasing of grain yield, 19 - 88 %, through indirect selection for yield components was comparable with that of yield components, 37 - 85 %, through direct selection for each yield component.

Average h^2 was 0.68 and G was 7.2 for S1 population. The heritability values and genetic gain for yield and yield components obtained of S2 population were lower than that of S1 population. Average h^2 was 0.62 and G was 2.7 for S2 population. In addition, the genetic correlations between grain yield and each yield components were relatively stable in S1 and S2 population.

original population.				
Genotype	No. of prod. panicles	Panicle weight (g)	Grain weight per panicle (g)	Grain yield per plant (g)
Selected for high:				
grain yield per plant	2.0 ab	30.3 a	11.5 a	18.0 b
grain weight per panicle	2.4 a	23.6 b	9.4 b	22.4 a
panicle weight	2.4 a	18.9 bc	6.3 b	20.7 ab
no.of prod. panicles	2.5 a	21.2 b	7.7 b	14.1 c
Selected for low;				
grain yield per plant	1.5 b	11.8 d	4.1 d	7.8 d
grain weight per panicle	1.9 ab	12.2 d	4.3 d	6.8 d
panicle weight	2.0 ab	12.8 cd	3.7 d	7.8 d
no.of prod. panicles	1.7 ab	11.8 d	4.4 d	8.2 d
Original population	1.4 b	13.8 cd	5.1 cd	11.9c
Mean	1.9	17.4	6.3	13.1
c.v. (%)	18.5	15.8	12.6	37.5

Table 11. Mean values for selected characters of 8 genotypes after two recurrent selection cycles and

Means followed by a common letter within a column are not significantly different at 5% level according to ANOVA protected LSD test.

Genotype	Plant height (cm)	Upper part dry weight per plant (g)	Harvest index (%)	Panicle length (cm)
Selected for high:				
grain yield per plant	88.7 a	35.5 a	66.0 ab	22 1 a
grain weight per panicle	e 79.2 a	25.8 a	87.5 a	21.6a
panicle weight	76.7 a	34.6 a	44.5 b	21.7a
no.of prod. panicles	69.3 a	20.7 ab	93.5 a	21.8a
Selected for low:				
grain yield per plant	77.1 a	13.9 b	53.5 ab	20.5 ab
grain weight per panicle	e 83.0 a	16.6 b	51.5 ab	14.3 cd
panicle weight	77.0 a	11.7b	64.5 ab	17.4bc
no.of prod. panicles	78.8 a	21.1 ab	38.0 b	19.6 ab
Original population	72.8 a	17.3 b	41.5 b	15.7 c
Mean	78.1	21.9	60.1	19.4
c.v. (%)	13.3	30.0	28.3	8.4

Table 12. Mean values for non selected characters of 8 genotypes after two recurrent selection cycles

and original population.

Means followed by a common letter within a column are not significantly different at 5% level according to ANOVA protected LSD test.



Fig. 3. Changes in mean values for selected (a) and non selected characters of genotypes after two selection cycles for yield and yield components.

GY, GW, PP, PW and OP; genotypes selected for grain yield per plant (g), grain weight per panicle (g), number of productive panicle, panicle weight (g) and original population.

two recurrent selecti			
Characters	G	h^2 x ₂ high - x ₂ low	_
		x_1 high - x_2 low	
Grain yield per plan	6.1	0.90	_
Grain weight per panicle	2.2	0.47	
Panicle weight	2.6	0.47	
No. of prod. panicles	0.6	0.67	

Table 13. Realized genetic gain (G) and heritability values (h²) for yield and its components after

 x_2 high and low; x_1 high and low; means of selected genotype for high and low after 2nd and 1st selection cycle, respectively. G was measured from (x_2 sel- x_2 op.)/2.

No. of productive	Panicle weight	Grain weight	Grain Yield
panicles	(g)	per panicle (g)	per plant(g)
No. of productive panicles -	0.51	0.87	1.00
Panicle weight (g)	-	0.58	0.73
Grain weight per panicle (g)		-	1.00
Grain yield per plant (g)			-

Table 14. Genetic correlations among yield and its components after two recurrent selection cvcles

Discussions

The higher values of genotypes selected for high grain yield, grain weight, number of productive panicles and panicle weight for those characters than those of original population and genotypes selected for the low (Table 11) revealed that the selection improved the characters. This also revealed the effectiveness of recurrent selection procedure practiced in the characters. In addition, as the non selected characters also were improved by selection (Table 12), the procedure was also effective for non selected characters as upper part dry weight, harvest index and panicle length.

A fairly large genetic gain (6.1) and heritability value (0.90) for grain yield led to the possibility for further higher grain yield gain by recurrent selection. In addition, the genetic gain for panicle weight in this study (2.6) was comparable with results reported in pearl millet by Shekhawat et al. (1993) as 3.7, 2.0 and 1.7 using mass selection, full-sib selection and half-sib selection, respectively.

Direct selection for grain yield requires relatively expensive yield trials and environmental conditions may reduce the expression of genetic potential for yield (Zeilani-khanghah et al., 1993). The genetic correlations of grain weight, number of productive panicles and panicle weight to grain yield were high (Table 14), and the close relationships between yield components and yield were obtained. This indicated that increase in those yield components had direct effect on grain yield and that selection for higher grain yield through the yield components might be successful. Table 15. Direct and indirect selection effects for grain yield and its components.

	Percentage increasing for character itself	Percentage increasing for grain yield per plant
Selection for grain yield per plant	101	-
Selection for grain weight per panicle	85	88
Selection for no. of productive panicles	s 79	19
Selection for panicle weight	37	74



The high % increasing of grain yield by both direct selection for grain yield and indirect selection through yield components indicated the effectiveness of recurrent selection procedure for grain yield practiced in this study. However, since they were not significantly different, as shown in Table 11, the effectiveness of direct selection was comparable to indirect selection through yield components for increasing grain yield.

In conclusion, recurrent selection procedure practiced in this study was effective for increasing both selected and non selected characters. The genetic gain and heritability value for grain yield was fairly large and further higher grain yield by recurrent selection might be possible. As the genetic correlations were high and the close relationships between yield components and grain yield were identified, selection for higher grain yield through the yield components was suggested. As % increasing of grain yield (101 %) with direct selection and (19 - 88 %) with indirect selection was observed, effectiveness of direct selection and indirect selection was comparable.

III. GENOTYPE x ENVIRONMENTAL INTERACTION

1. Selection for Low Temperature Germination

Introduction

There are many advantages in early planting of the crops. Depending on the case, early planting allows safe harvesting before the onset of rains or frosts that may decrease grain quality, enables the marketing of an early and competitive produce (Blum, 1988) and increases number of options available for subsequent crops (Kane and Grabau, 1992).

Temperature is often of overriding importance for seedling growth, especially in chilling-sensitive species (Richner et al., 1996). Law temperature at sowing delays both germination and plant emergence, lengthens the crop cycle and increases production costs by demanding greater irrigation time (Otubo et al., 1996). Low temperature became one of the main limiting factors for seed germination in the early spring planting and carried an effect on subsequent seedling growth and its field performance. An understanding of the low temperature germination and its effect on growth, thus, would facilitate cultivar development for early spring planting adaptation.

Studies on germination at a low temperature and its effect on the subsequent growth in several crops were reported (Bertin et al., 1996; Equiza et al., 1997; Redona and Mackill, 1996; Yoshida and Sumida, 1996). Very limited studies, however, concerning the pearl millet for early spring planting were available.

The experiment was carried out 1 to study germination response patterns of two

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pearl millet populations on several levels of temperature, 2 to select genotype germinating at a low temperature, and 3 to evaluate the selected sub-populations for yield and yield components in field.

Materials and methods

. Two pearl millet populations, tall and short statured, were used as materials. The former was originated from several breeding materials of early maturing and the latter from open pollinated variety "ICMV89074", both of which were kindly provided by Dr.C.T. Hash of ICRISAT (India), and were later grain increased by open pollination in several seasons including May and August sowing.

(1) Germination experiment

Experiment was conducted in a factorial pattern of completely random design with 4 replications on from 4 December 1995 to 10 February 1996.

Treatments consisted of two, tall and short statured, populations and 4 levels of temperature, i.e. 15, 20, 25 and 30 °C. A filter paper in a 7 cm diam. petri dish was used as medium. Amount of 50 seeds of populations were germinated in a petri dish for levels of temperature in an incubator. There were, therefore 1600 seeds of 32 units of experiments. One mL of sterilized water was supplied daily on each of petri dish, and % germination, root length (mm), shoot length (mm), and shoot-root ratio, were measured 5 days after planting.

Significance of treatment effects was examined using analysis of variance procedure and differences among mean values were examined using protected least significant difference test procedure (Steel and Torrie, 1980). Regression equations of % germination, root length, shoot length and shoot-root ratio to temperature were measured, and the coefficients of determinations were computed.

(2) Field experiment

For materials preparation, 50 seeds were germinated on 18 April 1996, on a filter paper in a 18 cm diam. and 5 cm height petri dish at a 15 °C incubator.

After 7 days, the highest 10 % root length and the highest 10 % shoot length of the germinated seeds were selected. Materials were transplanted to paper pots and grown in a greenhouse for about 2 weeks and transplanted to the field on 10 May.

For field experiment, a factorial pattern with randomized complete block design in 3 replications was applied. Treatment consisted of six sub-population, i.e. original short statured sub-population (S1), the highest 10 % shoot length of short statured sub-population (S2), the highest 10 % root length of short statured sub-population (S3), original tall statured sub-population (S4), the highest 10 % shoot length of tall statured sub-population (S5), the highest 10 % root length of tall statured sub-population (S6), and two planting densitiesie. 10 plants m^2 (D1) in a 2 m^2 plot and 20 plants m^2 (D2) in a 1 m^2 plot. There were, therefore, 36 units of experiments.

Spacing as 20 x 50 cm (D1) and 10 x 50 cm (D2) within and between rows, and 0.8 g N, 0.8 g P₂O₅ and 0.8 g K₂O fertilizer per m² were applied. Plant height (cm) and number of productive panicles were measured after heading. Medium 5 plants were harvested from each plot as samples on 13 August 1996 and panicle length (cm), panicle weight (g), grain weight (g) and grain yield (gm²) were measured after air-dried. Data were subjected to analysis of variance continued by protected least significant difference test procedures.

Results

(1) Germination experiment

Mean squares of analysis of variance for different temperature levels and sub-populations effects on the characters were shown in Table 16. Total treatment had significant effects on all of four characters. Temperature levels individually, had significant effect. Neither significant effect, however for sub-populations nor its interaction with temperature levels were detected.

Mean values for % germination, root length, shoot length, and shoot-root ratio in each treatment were presented in Table 17. In low temperature the four characters declined in its performance. The decline in root growth in low temperature involves a reduced capacity for water and mineral uptake, with subsequent, secondary nutritional effects on plant growth (Blum, 1988).

Table 16. Mean squares of % germination, root length, shoot length, and shoot-root ratio of pearl millet in the different temperature conditions.

Source	df	% germination	Root length (100 mm))	Shoot length (100 mm)	Shoot-root ratio
Treatment	1	182*	45.48**	17.82**	432.83**
Population (P)	3	34	0.02	0.09	0.68
Temperature (T)	3	309**	104.33**	41.32**	1000.22**
РхТ	3	104	1.79	0.23	9.48

*,**; significant at 5 and 1% level, respectively.

Factor	% germination	Root length (mm)	Shoot length (mm)	Shoot-root ratio (arc sin)
Population				
Tall	87a	57a	31a	32a
Short	92a	56a	30a	31a
Temperature °C				
15	70a	5a	1a	18a
20	94b	58b	24b	28b
25	97b	79c	45c	39c
30	95b	84c	52d	42c
c.v.(%)	18.3	14.7	13.7	11.8

Table 17. Mean values of the % germination, root length, shoot length and shoot-root ratio of pearl millet in the different temperature conditions.

For each factor, means followed by a common letter within a column are not significantly different at 5% level according to protected LSD test.

No significant difference between 25 and 30 °C treatments, however, were observed, except shoot length. Coefficient of variation were between 11.8 and 18.3, revealing that characters were not too influenced by environmental condition fluctuations.

Varied % germination, root length, shoot length, and shoot-root ratio of tall and short population means as response patterns to the levels of temperature are presented in Fig. 4. Regressions of root length and shoot length on temperature for the both of populations were obtained as follows:

Y (tall pop. shoot length) = -49.34 + 3.58 X (R = 0.911)

Y (tall pop. root length) = -66.37 + 5.48 X (R= 0.844)

Y (short pop. shoot length) = -44.47 + 3.31 X (R = 0.933)

Y (short pop. root length) = -53.08 + 4.87 X (R = 0.755)

where, X: temperature, A: coefficient of determination.

It is interpreted from these equations that increasing of one temperature unit could be followed by increasing of germination characters unit proportional to those of regression coefficient value. From the X values of Y=0, in tall statured population, seeds needed higher than 13.8 °C for shoot initiation and higher than 12.1 °C for root initiation. In short statured population, seeds needed higher than 13.4 °C for shoot initiation and higher than 10.9 °C for root initiation. These were confirmed using same materials for 10 °C, showing no seeds germination (data not shown).



Fig., 4 Germination response of pearl millet populations on levels of temperature.

Coefficient of determinations varied between 0.75 and 0.93, revealing that 75 - 93 % of the temperature-germination characters relationship may be explained by those equations.

(2) Field experiment

Mean squares of analysis of variance for sub-population yield and yield components values in the two planting densities are shown in Table 18. There were significant effects of total treatment on plant height, panicle length and grain yield. But, no significant effects on the number of productive panicles and grain weight were observed. The significant effects were contributed by the effect of sub-population for plant height and panicle length, and by the effect of plant density for grain yield. Significant interaction of sub-population x plant density was observed only for grain yield and no interaction was detected for the other characters.

Mean grain yield and yield components of sub-population evaluated in the field for low temperature germination pretreatment are shown in Table 19. Populations separated into two groups being significantly different between them, but not significantly different to each other within a group for plant height and panicle length. The 10 % highest root length of short statured sub-population (S3) and the 10 % highest shoot length of short statured sub-population (S2) were not significantly different from the original short statured sub-population (S1).for yield and yield components (Table 19). The same phenomena were also shown in the tall statured sub-populations, S5 and S6.

Table 18. A Mean squares for pearl millet grain yield and its components in the different sub-population and planting densities.

Source	df	Plant height (10 m)	No.of prod. panicles	Panicle length (cm)	Panicle weight (g)	Grain weight per panicle (g)	Grain Yield per m ² (100 g)
Replication	2	4.6	0.17	8.0	57.1	29.3	76
Treatment	11	282.3**	* 2.01	16.9*	62.2	31.2	439**
Sub-population (S)	5	612.2**	1.36	29.6**	69.9	31.4	51
Density (D)	1	9.1	3.61	2.1	49.1	15.4	4243**
S x D	5	24.1	2.34	7.3	57.2	34.2	67*

*,**; significant at 5 and 1% level, respectively.

0						
Factor	Plant height (cm)	No of prod panicles	. Panicle length (cm)	Panicle weight (g)	Grain weight per panicle	Grain yield per m ² . (g)
Population						
$\mathbf{S1}$	124 a	2.67	26.5 a	37.2 a	26.4 a	400 a
S2	131 a	1.93	24.3 ab	31.2 a	22.8 a	330 a
S3	117 a	2.03	24.4 ab	39.3 a	27.6 a	391a
S4	184 b	2.63	20.8 c	34.7 a	24.7 a	380 a
S5	181 b	3.23	20.9 c	31.1 a	21.7 a	350 a
S6	180 b	2.40	22.9 bc	32.0 a	22.9 a	340 a
Planting de	ensity					
D1	154 a	2.80 a	23.5 a	35.4 a	25.0 a	257a
D2	151 a	2.17 a	23.1 a	33.1 a	23.7 a	474b
c.v.(%)	10.3	41.90	10.9	16.8	17.3	13.3

Table 19. Mean yield and its components of pearl millet sub-populations evaluated for low temperature germination.

For each factor, means followed by a common letter within a column are not significantly different at 5% level according to protected LSD test. S1 - S6 and D1 - D2 are original short or tall populations, selected for long shoot or long root, and are 10 and 20 plants per m sq density, respectively.

Average of grain yields was 257 gm⁻² and 474 gm⁻² for 10 m⁻² and 20 m⁻² planting densities, respectively. The values were higher than those resulted by M'Khaitir and Vanderlip (1992) and nearly similar to be reported by Yoshida and Sumida (1996). A plant height, number of productive panicles, panicle length, panicle weight, and grain weight tended to decrease as increasing of planting density. Grain yield increased as increasing of planting density. These results agree with M'Khaitir and. Vanderlip (1992) in sorghum and pearl millet.

Varied grain yield and yield components of sub-populations as responses to the planting densities are shown in Fig. 5. Sub-population x planting density interaction had significant effect on grain yield, but no significant effect on the other characters. M'Khaitir and Vanderlip (1992) also reported significant interaction of population density x cultivar for pearl millet grown in Manhattan on 1989. Cox (1996) reported significant interaction of hybrid x planting density for grain yield and dry matter production of maize. Significant interaction of sub-population x planting density on grain yield in this study means that yield difference between two planting densities differed among sub-populations. Fig. 5 shows that grain yield of the short statured population groups tended to be higher than that of the tall statured population groups in the low planting density. Grain yield of the short statured population groups however, tended to be lower than that of the tall statured population groups in the high planting density.



Fig. 5 Sub-populations response on two planting densities after low temperature germination pretreatment. S1- S6; original short or tall populations, selected for long shoot or long root, respectively

 \Box 10 plants per m², \blacksquare 20 plants per m².
Discussions

All characters were different with changing temperature levels, but no effect of population was observed. It means that the temperature effects contributed more substantially than population effects to the total variability in characters. In addition, no significant population x temperature interaction for characters means that both populations have same response pattern to the temperature in germination parameters observed. Same result was reported by Wilson et al. (1992) with Brassica and by Equiza et al. (1997) with wheat.

As the non significant difference between S2 and S3 for yield components, as well as between S5 and S6, was observed, the sub-populations may have compensated their growth of root and shoot in field condition for low temperature germination pretreatment. Even if chilling stress in roots may be severe enough to cause irreversible damage, the recovery of root growth and function after chilling is possible, depending on the intensity and duration of stress (Blum, 1988).

As the average grain yield after in low temperature pretreatment was nearly similar to Yoshida and Sumida (1996) at May and August sowing, the low temperature (15 °C) pretreatment in this study is still within the stress tolerance limitation, showing that earlier sowing than May sowing might be possible. In conclusion, lower temperature declined germination, genotypes gave same response to temperature levels in the linear pattern, and temperature had more contribution than genotype on the germination variability. Plants in the field may have a recoverability after 15 °C pretreatment during germination and selection for early spring planting of pearl millet may be possible.

2. Genetic Gain and Heritabihty of Seedling Characters Selected at Low

Temperature

Introduction

To develop early planting genotypes of pearl millet, information concerning germination at low temperature is important because low temperature stress is the most common environmental stress for germination (Blum, 1988). Estimation of genetic gain and heritability of seedling characters at low temperature would become a valuable contribution to the selection for early spring planting adaptation.

Objectives of this selection were 1 to examine the effect of one selection cycle on seedling characters at low temperatures, 2 to estimate heritability values and genetic gain of the characters, and 3 to examine the relationship between seedling characters and yield components, using the materials obtained in the previous section.

Materias and Methods

One selection cycle for shoot and root length 5 days after seed germination at 15 C was practiced with two pearl millet populations; short statured (S1) and tall statured (S4) populations. S1 originated from an open pollinated variety "ICMV89074 " and S4 from several early maturing breeding materials. These seeds were increased by open pollination in several seasons including May and August sowing.

(1) Selection procedure

Fifty seeds of S1 and S4 were placed on a filter paper in a petri dish, 9 mm in diameter, 4 petri dishes per group. The petri dishes were kept at 15 °C for germination. One mL of distilled water was supplied to each petri dish daily. After five days of incubation, shoot length of germinated seeds was measured. The seedling with the longest 10 % and the shortest 10 % shoots were selected from each group and they were replanted in a paper cup, $5 \times 5 \times 5$ cm in size, filled with soil, and placed in the greenhouse until they were transplanted to pots for seed production. The same procedure was applied for root length selection. A total of eight sub-populations were created from 2 parents x 2 characters x 2⁻ way selections.

(2) Seed production of sub-populations

The seedlings were transplanted to plastic pots filled with about 4 kg sifted soil, 0.8 g N, 0.8 g P₂O₅ and 0.8 g K₂O per pot on May 1996 in a greenhouse. Two plants per pot and 6 pots per sub-population were arranged. A total of 120 plants in 60 pots, including S1 land S4, were prepared. Panicles were bagged before heading, polycrossed among individuals manually within a sub-population, and harvested on August 1996.

(3) Evaluation of germination at low temperatures

The seedling characters from the seeds of sub-populations and S1 and S4 were examined at a low temperature (15 °C). Four petri dishes were used for each sub-population as replications of completely randomized design. The data were subjected to analysis of variance according to Steel and Torrie (1980) using IRRISTATS 3/93 (IRRI, 1993). The mean value of generation for each character was compared to their original parental mean value to estimate leritability and genetic gain values.

(4) Yield components evaluation

Seeds from sub-populations, namely: A long-shoot population (S2) and a long-root population (S3) selected from an S1 and a long-shoot population (S5) and a long-root population (S6) selected from S4, were germinated in a petri dish with a filter paper on 23 July, transferred to paper pots on 31 July and transplanted to field on 17 August 1996. Each sub-population with 20 seedlings was grown in two rows per plot in a randomized completely block design with 4 replications. Spacing of 50 x 10 cm between and within rows per plot, and 0.8 g N, 0.8 g P_2O_5 and 0.8 g K_2O per m² were applied. Plant height, number of productive panicles, panicle length and panicle weight were observed as yield components and their correlations to the seedling characters at low temperatures were calculated.

(5) Estimation of heritabihty

Heritability $(h_1^2 \text{ and } h_2^2)$ was estimated using two formulas (Falconer, 1981; Fehr, 1987a):

$$x_1$$
 high- x_1 low

 $h_1^2 =$

xº high- xº low

where, x_0 high and. x_0 low, are mean values of the character of individuals selected from the original population for high and low characters respectively, and x_1 high and x_1 low, are mean values of the character of population selected after mating the individuals for high and low characters, respectively.

$$h_2^2 = \frac{x_1 \operatorname{sel} \cdot x_1 \operatorname{op}}{x_0 \operatorname{sel} \cdot x_0 \operatorname{op}}.$$

where, x_0 sel, x_0 op, x_1 sel and x_1 op, are the mean values of the character of individuals selected from the original population, that of the original population, that of the population derived from mating the selected individuals and that of the original population grown with x_1 sel, respectively. The h_2^2 was calculated from the results of upward and downward selection responses. The realized genetic gain was calculated as:

G= x1high - x11ow and G= x1se1 - x1op.

Results

Table 20 shows the mean squares of analysis of variance for seedling characters after one selection cycle. Selection had a significant effect on the seedling characters, except shoot-root ratio. Sub-populations differed in shoot length, root length, and % germination, as well as populations pooled across sub-populations. No significant effect of selection on shoot-root ratio revealed that this character was least influenced by selection.

Table 21 shows the mean values pooled across sub-populations, parents and each sub-population.

(1) Seedlig characters

The % germination, shoot length and root length of the short population were higher than that of the tall population (Table 21). Sub-populations pooled across parents selected for a long shoot or root showed a higher % germination, shoot length and root length than the original population.

In the tall population, the shoot length did not differ significantly among the sub-populations selected for a long shoot and root and the original population. The same results were obtained in the short population.

Source	df	% germination	Shoot length (mm)	Root length (mm)	Shoot-root ratio (arc. sin)
Replication	3	8.27	0.04	0.63	2.35
Treatment	9	1186.48**	1.55**	21.55**	12.68
Pop. across sub-population	1	1488.41**	3.01**	32.97**	0.93
Sub-population	4	1954.85**	2.38*	32.66**	19.43
Parents vs. sub-population	4	342.65*	0.35	7.59	8.78

Table 20. Mean squares by ANOVA for germination and seedling characters after one selection cycle for germination at a low temperature in pearl millet.

*;** significant at 5 and 1% level, respectively.

Factor .	% germination	Shoot len (mm)	gth Root ler (mm)	ngth Shoot-root ratio
Pooled across sub-population				
Tall population	51.7 a	2.06 a	7.60 a	17.9 a
Short population	63.9 b	2.61 b	9.41 b	18.1 a
Pooled across parents				
Original population	47.0 a	2.16 a	8.40 a	16.2 a
Long shoot sub-pop.	79.5 b	2.90 b	10.66 b	17.9 a
Long root sub-pop.	69.2 b	2.91 b	10.45 b	18.0 a
Short shoot sub-pop.	44.7 a	1.72 a	6.61 a	17.2 a
Short root sub-pop.	46.5 a	1.98 a	6.43 a	20.4 a
Sub-population				
Original tall pop.	47.5 b	1.90 bc	7.78 b	l4.8 a
Long shoot tall pop.	71.5 с	2.83 c	10.56 c	17.4 a
Long root tall pop.	68.0 c	2.84 c	10.48 a	17.5 a
Short shoot tall pop.	28.0 a	1.16 a	4.45 a	17.4 a
Short root tall pop.	43.5 b	1.59 ab	4.74 a	21.9a
Original short pop.	50.5 b	$2.42~{ m c}$	9.02 bd	17.6 a
Long shoot short pop.	87.5 d	2.98 с	10.75 d	18.3 a
Long root short pop.	70.5 c	2.99 c	$10.42 \operatorname{cd}$	18.5a
Short shoot short pop.	61.5 c	2.28 b	8.77 bd	17.1 a
Short root.short pop.	49.5 b	2.38 a	8.12 bc	18.9 a
c.v. (%)	12.8	21.1	20.6	16.5

Table 21. Mean values of germination and seedling characters after one

selection cycle for germination at a low temperature in pearl millet.

For each factor, means followed by a common letter within a column are not significantly different at 5% level according to ANOVA protected LSD test.

In the sub-populations pooled across parents, the root length of the population selected for a long shoot or long root was similar to each other. However, both were significantly different from the original population.

(2) Estimation of heritability

Table 22 shows the genetic gain realized at a selection intensity of 10 % for the seedling characters. Genetic gain calculated from (high - low selection) was 5.74 and 2.30 for root length, and 1.67 and 0.70 for shoot length, in the tall and short populations, respectively.

The genetic gain calculated from (selection - population mean) of long root was 2.70 and 1.40 in the tall and short population, respectively and that of short root was -3.04 and -0.90, respectively. The genetic gain of long shoot, 0.93 and 0.56, respectively, was similar to that of short shoot length, -0.74 and -0.14, in the tall and short population.

Table 22 shows the heritability values for seedling characters. The values of h_1^2 ranged from 0.28 to 0.76 and the values of h_2^2 from 0.09 to 0.99. Heritability values, 0.76 and 0.37 for root length in the tall and short populations, respectively, were similar to those for shoot length, 0.69 and 0.28, respectively.

Considering the direction of selection, long shoot or root is a more important character than short shoot or root. Long shoot showed higher heritability values, 0.99 and 0.66 in the tall and short populations, respectively than short shoot, 0.50 and 0.09, respectively. Higher heritability values of long root 0.95 and 0.52 in the long and short population, respectively, than short root (0.58 and 0.26) in the tall and short population were also obtained.

Character	G (\mathbf{x}_1 high - \mathbf{x}_1 low)	h_1^2
Shoot length tall pop.	1.67	0.69
Root length tall pop.	5.74	0.76
Shoot length short pop.	0.70	0.28
Root length short pop.	2.30	0.37
	G(x_1 se1- x_1 op)	${{ m h_2}^2}$
Tall population		
Long shoot	0.93	0.99
Long root	2.70	0.95
Short shoot	-0.74	0.50
Short root	3.04	0.58
Short population		
Long shoot	0.56	0.66
Long root	1.40	0.52
Short.shoot	-0.14	0.09
Short root	- 0.90	0.26

Table 22. Genetic gain (G) and heritability (h²) of characters selected for 1 germination at a low temperature in pearl millet.

G is the genetic gain at a selection intensity of 10 %, and h_1^2 and h_2^2 are heritabilities calculated from the values of (high selection-low selection) and (selection - population mean), respectively.

(3) Yield components

Table 23 shows the mean square values for yield components of sub-populations selected under a low temperature and grown in a field. Sub-populations significantly differed in plant height, panicle length and panicle weight, but not in the number of productive panicles per plant. The mean values for various characters of sub-populations are shown in Table 24. The values in sub-populations selected from the tall population (S5 and S6) were significantly different from those of the sub-populations selected from the short population (S2,S3) in all characters except for number of productive panicles. Plant height was higher in the tall population group (S4,S5,S6) than the short population group (S1,S2,S3), but panicle length of the former was shorter than the later. No significant difference for plant height was observed among S2, S3, and S1 or among S5, S6 and S4.

In the short population, the panicle of S2 was significantly longer than that of S3 and S1, but that of S3 was not significantly different from that of S1. The panicle weight of S2 was significantly higher than that of both S3 and S1, but that of S3 was not significantly different from that of S1. However, in the tall population, no significant difference was observed in panicle length among S5, S6 and S4. The panicle weight of S6 was significantly higher than that of S4, but not that of S5. Table 23. Mean squares by ANOVA for yield components of sub-population selected for germination at a low temperature.

Source	df	Plant height (cm)	No. of prod. panicle	Panicle length (cm)	Panicle weight (g)
Replication	3	383*	0.208	7.0	39.8*
Sub-population	5	7075**	0.028	24.1*	47.7**

*,**; significant at 5 and 1% level, respectively.

Sub-population	Plant height (cm)	No. of prod. panicles	Panicle length (mm)	Panicle weight (g)
S 1	94 a	1.31 a	20.6 ab	17.4 a
S2	96 a	1.45 a	25.6 c	26.1 c
$\mathbf{S3}$	91 a	1.25 a	22.4 b	20.2 a
$\mathbf{S4}$	169 b	1.31 a	18.9 a	19.8 ab
$\mathbf{S5}$	173 b	1.31 a	19.9 a	24.4 bc
$\mathbf{S6}$	170 b	1.21 a	19.6 a	24.9 с
c.v. (%)		19.8	7.6	14.7

Table 24. Mean value of yield components of genotypes selected for germination at a low temperature.

For each factor, means followed by a common letter within a column are not significantly different at 5% level according to ANOVA protected LSD test. For S1 \sim S6, see text.

(4) Correlations between seedling characters and yield components

Table 25 shows the correlation coefficients between seedling characters at low temperatures and yield components in the field among sub-populations. The values ranged from 0.135 and 0.684. Plant height was negatively correlated to shoot and root length. However, other pairs of characters showed positive correlation.

Discussions

The % germination of selected sub-population was higher than that of parent, both in short and tall populations, indicating that selection for long shoot or root increased the % germination at low temperature. In addition, as the original and sub-population selected for long shoot or root of short population performed higher values for percent of germination than that of the tall ones, short population might be more adapted for low temperature germination.

Since sub-populations selected for long shoot or root showed higher values for shoot length than the original ones, selection for long shoot or root was effective for the selection of long shoot characters. The same phenomena were observed for long root. Therefore, it is clear that selection for long shoot or root was effective for the selection of both shoot and root characters.

Table 25	. Correlations be	etween gern	nination an	d seedling	characters	and yield	components
	among sub-pop	oulations sel	ected for ge	rmination	at a low te	mperature	2.

	Shoot length	Root length	Plant height	Panicle length	Panicle weight
Shoot length	1	0.684*	-0.193	0.519	0.503
Root length		1	-0.217	0.392	0.553
Plant height			1	0.534	0.135
Panicle length				1	0.484
Panicle weight					1

*; significant at 5% level.

The difference between the genetic gain obtained from upward and downward selection was observed for root length, indicating an asymmetric selection response for the character.

As heritability values in the tall population were higher than those in the short population, the tall population might be more heterogeneous and had a higher variability than the short population. Fehr (1987a) explained that the estimation of heritability was influenced by the amount of genotypic variance. This may explain the higher genetic gain for seedling characters in the tall population than in the short population. In addition, heritability values for long shoot or root are higher than for short shoot or root, further selection for longer shoot or root might be possible.

In the short population, panicle length and panicle weight values of sub-population selected for longer shoot were higher than that of the original one. In the tall population, panicle weight value of sub-population selected for longer root showed higher than that of the original. It showed that selection for longer shoot increased panicle length and panicle weight of the short population and selection for longer root increased panicle weight of the tall population.

The correlations of shoot length to panicle length (0.519) and to panicle weight (0.503) and that of root length to panicle weight (0.553) suggest a relationship between the seedling characters and yield components.

In conclusion, the selection had a significant effect on seedling characters at low temperatures. Selection for longer shoot or root increased % germination at low

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temperatures, panicle length and panicle weight in a field. Shoot length was always correlated with root length. Shoot and root length had high heritability and may be useful as selection criteria at low temperatures. Further genetic gain for seedling characters could be obtained, especially for longer shoot and root length.

3. Genotype x Environment Interaction in Selected Genotypes

Introduction

Changes in the relative performance of genotypes across environments lead to the importance of genotype x environment (G x E) interaction study. Many studies were conducted to explore the information regarding with genotype response to different season and/or spacing and their interaction.

Studies on genotype x cropping season interaction (Oosato et al., 1996), and effect of seeding rate (Gravois and Helms, 1992) in rice, effect of planting density (Cox, 1996) and seasons (Prasad and Singh, 1990; Mahajan and Khehra, 1992) in maize, plant density in soybean (Board et al., 1996; Wells, 1993), plant density in sorghum (M'Khaitir and Vanderlip, 1992) and sowing date and season interaction in navy bean (Redden, et al., 1997) were reported. There are many studies in pearl millet grain yield on heterosis, stability and the interaction in different spacing, season and/or planting density (Dave and Joshi, 1995; M'Khaitir and Vanderlip, 1992; Pethani, 1993; Pethani and Dave, 1992). However, little information is available on the influence of genotypes selected for low temperature germination x season interaction on grain yield and its components in pearl millet which is grown in different planting density.

Two season field experiments were conducted to study 1 response of genotypes to spring and fall sowing, 2 effect of spacing and 3 their interaction on grain yield and yield components of pearl millet.

Materials and methods

Two genotypes of tall and short populations were used as original materials. The original seeds were obtained from ICRISAT and they were increased by open pollination in several seasons including May and August sowing. Seeds were germinated in a 15 C incubator for 5 days. Seedlings with the longest and the shortest 10% shoot and root length were selected and replanted in ziffy paper cups filled with soil in a greenhouse. After 3 weeks, seedlings were transplanted to the field. Six genotypes, namely S1, S2, S3, S4, S5 and S6 as original, long shoot and long root of short and tall populations were included. The characteristic of genotypes were shown in Table 26.

(1) Spring season experiment

Seedlings were transplanted to the field on 10 May 1996. Randomized complete block design with 2 replications was applied. Two spacings as 50 x 10 and 50 x 20 cm Table 26. Genotypes selected by low temperature germination.

Genotypes	Characteristic
$\mathbf{S1}$	Original short population
S2	Selected for shoot length of short population
S3	Selected for root length of short population
S4	Original tall population
S5	Selected for shoot length of tall population
$\mathbf{S6}$	Selected for root length of tall population

between rows and within rows were arranged as treatment. A plot consisted of 2 rows with 20 plants. Size of a plot was one square meter for 50 x 10 cm spacing and 1 x 2 m for 50x 20 cm spacing. Amount of 0.8 g N, 0.8 g P_2O_5 , and 0.8 g K₂O per m² were fertilized as a basal dressing. Plant height (cm), number of productive panicles per plant, panicle weight (g per panicle), panicle length (cm), grain weight per panicle (g) and grain yield per square meter (g) were observed with average 5 plants per plot. Plants were harvested on 13 August 1996.

(2) Fall season experiment

Same experiment as spring season experiment was conducted in a field not too far from the spring season field experiment. Six genotypes selected by the same pretreatment as spring sowing were planted on 17 August 1996. Treatment, experiment design and data collection were same. Plants were harvested on 29 October 1996.

All two experiments data were subjected to analysis of variance continued by protected LSD test (Steel and Torrie, 1980) using IRRISTAT 3/93 (IRRI, 1993).

Results

Mean squares of analysis of variance for yield and yield components were shown in Table 27. Genotypes differed in plant height and panicle length, but not in number of productive panicles, panicle weight, grain weight per panicle and grain yield. Significant effect of spacing was observed for number of productive panicles, panicle weight and grain yield, but not for plant height, panicle length and grain weight per panicle.

Table 27. Mean squares by ANOVA for pearl millet grain yield and its components in different spacing and season.

Source	df	Plant height (100 cm)	No. of prod. panicles	Panicle weight (g)	Panicle length (cm)	Grain weight pep panicle (g)	Grain yield per m ² (1000 g)
Replications	1	5.6	0	95.1*	9.7	19.2	22.9*
Genotypes (S)	5	118.2**	0.74	9.7	33.8**	7.5	0.2
Spacing (SP)	1	3.3	4.08*	139.2*	16.28	70.6	236.8**
S x SP	5	1.0	1.63*	61.4*	6.3	27.9	3.6
Seasons (T)	1	49.7**	18.75**	1727.6**	56.8**	806.9**	116.1**
S x T	5	1.4	0.83	106.2*	6.9	55.3*	9.8
SP x T	1	2.3	0.75	23.4	7.6	38.9	81.5**

*,**; significant at 5 and 1 % level, respectively.

Different season influenced all characters significantly. In Table 28, mean values of grain yield and yield components in different genotype, spacing and season were shown. In Figs. 6 and 7, changes in yield and its components as responses to interaction of S x SP and S x T were presented.

(1) Effect of genotypes

S4, S5 and S6 showed higher mean values than S1, S2 and S3 only for plant height and vise verse for panicle length. Though genotypic difference was significant (Table 27), no significant differences were observed among S1, S2 and S3 in one group or among S4, S5 and S6 in the other group for the plant height and panicle length.

(2) Effect of spacing

Spacing affected number of productive panicles, panicle weight and grain yield (Table 28). The number of productive panicles and panicle weight increased significantly and compensated for wider spacing. Conversely, decreasing grain yield was observed in wider spacing.

Mean values under 50 x 10 and 50 x 20 cm spacing varied in number of productive panicles as $1.4\sim2.0$ and $1.5\sim3.3$, in panicle weight as $23.9\sim28.3$ g and $25.1\sim36.1$ g and in grain yield as $346\sim409$ g m⁻² and $223\sim275$ g m⁻², respectively (Fig. 6).

No significant difference for panicle length and grain weight was observed with different spacings.

(3) Effect of season

Factor	Plant height (cm)	No. of prod. panicles	Panicle weight (g)	Panicle lengt (cm)	h Grain weight per panicle (g)	Grain yield per m ² (g)	
Genotype pool	ed across spacing	and seasons					
$\mathbf{S1}$	107 a	1.55 a	28.1 a	24.6 a	20.0 a	320 a	
S2	104 a	1.75 a	30.0 a	23.5 a	20.9 a	311 a	
$\mathbf{S3}$	111 a	2.22 a	27.6 a	23.4 a	19.6 a	317 a	
$\mathbf{S4}$	177 b	2.35 a	26.6 a	19.9 b	18.6 a	320 a	
$\mathbf{S5}$	177 b	1.81 a	28.1 a	20.9 b	21.2 a	325 a	
$\mathbf{S6}$	178 b	1.87 a	28.0 a	19.8 b	20.6 a	316 a	
Spacing poole	d across genotypes	s and seasons					
50x10cm	140 a	1.63 a	26.4 a	21.4 a	18.9 a	388 a	
50x20cm	145 a	2.22 b	29.8 b	22.6 a	21.4 a	248 b	
Seasons pooled across genotypes and spacing							
Spring	152 a	2.55 a	34.1 a	23.1 a	24.2 a	367 a	
Fall	132 b	1.31 b	22.1 b	20.9 b	16.0 b	260 b	

Table 28. Mean value for grain yield and yield components of pearl millet in different spacing and season.

Where: S1-S6, see Table 26. For each factor, means followed by a common letter within a column are not significantly different at 5 % level according to ANOVA protected LSD test.



Fig.6. Changes in yield components as responses to spacing of pearl millet genotypes.For S1-S6, see Fig.5.

For all mean values across genotypes and spacings, spring sowing was significantly higher than fall sowing (Table 28 and Fig. 8).

Climatic differences between both seasons contributed the significant effect of season (Fig.8). For spring sowing, mean daily temperature during the first and the last month was 19.4 °C and 27.1 °C, humidity was 64 % and 75 %, and precipitation was 50.5 mm and 113 mm, respectively. Mean daily solar radiation during spring sowing was 16.83 MJ m². For fall sowing, mean daily temperature during the first and the last month was 28.2 °C and 19.0 °C, humidity was 72% and 71 %, and precipitation was 179.5 mm and 72.0, respectively. Mean daily solar radiation during fall sowing was 15.43 MJ m². Average 95 days and 73 days from transplanting to harvesting under spring and fall sowing, respectively were recorded.

Higher mean values were obtained under spring than fall sowing as average 37 % for grain yield, 51 % for grain weight, 10 % for panicle length, 54 % for panicle weight, 95 % for number of productive panicles and 15 % for plant height, respectively.

(4) Difference among genotypes selected by low temperature

The low temperature germination pretreated in this study had no effect in general on the field performance of the plant in both spring and fall sowing. Genotypes selected by low temperature germination for shoot or root length of both short and tall populations were not significantly different from the original ones for all characters (Table 28).



Fig.7. Changes in yield components as responses to sowing season of pearl millet genotypes. For S1-S6, See Fig. 5.

(5) Effect of genotype x spacing interaction

Number of productive panicles and panicle weight were significantly affected by S x SP interaction (Table 27). For number of productive panicles, the interaction was due to the higher values of S3 and S4 in 50 x 20 than in 50 x 10 cm spacing and not significant difference of another genotypes. For panicle weight, the interaction was due to the higher values of S2 in 50 x 20 cm than in 50 x 10 cm spacing and no significant difference of another genotypes (Fig.8). For grain yield, though higher value in 50 x 10 cm than 50 x 20 cm spacing in all genotypes was observed, no significant interaction was detected.

No significant S x SP interaction for plant height, panicle length and grain weight were also detected. No significant genotype x row spacing interaction for yield was also reported in soybean (Board et al., 1996).

(6) Effect of genotypes x season interaction

For panicle weight and grain weight per panicle, S x T interaction was significant (Table 27). Panicle weight varied $28.4 \sim 39.8$ and $17.5 \sim 24.9$ g per panicle for spring and fall sowing, respectively. Grain weight varied $19.4 \sim 28.0$ and $12.4 \sim 19.1$ g per panicle for spring and fall sowing, respectively. The significant effect of S x T interaction in panicle weight and grain weight was due to the higher values of S2, S3 and S6 in spring than in fall sowing and no significant difference of another genotypes (Fig. 7). Sagar and Singh (1995) also reported the significant interaction of pearl millet genotype x environment for plant height, effective tillers, panicle length, panicle weight, grain yield and dry fodder yield.



Fig.8. Changes in means of yield components as responses to spacing by spring and fall season of pearl millet.

Dave and Joshi (1995) reported that season affected the clustering pattern in pearl millet.

Grain yield was 331~410 and 224~309 gm⁻² for spring and fall sowing, respectively. Yield values were comparable with Yoshida and Sumida (1996) as 371~451 and 164 ~239 g m⁻² under May and August sowing in Fukuoka, respectively and higher than yield of 1 634 and 2 386 kg ha⁻¹ in drought and rainfall condition, respectively in St. John, Kansas reported by M'Kaitir and Vanderlip (1992). Furthermore, pearl millet showed one of the fall sowing grain crops.

Mean values were less in fall than spring sowing for number of productive panicles as $1.2 \sim 1.4$ vs. $1.7 \sim 3.4$, and for panicle length as $18.8 \sim 24.8$ vs. $20.1 \sim 26.0$ cm. But, their degrees were comparable in their order (Fig. 7), resulting in no significant S x T interaction. No significant G x E interaction for plant height, panicle length, panicles number and grain yield of African pearl millet landrace populations (Ouendeba, et a1., 1995) and significant G x E interaction for grain yield of genotypes (Pethani, 1993; Pethani and Dave, 1992) were also reported.

Discussions

Higher mean values were obtained for number of productive panicles and panicle weight under 50 x 20 cm than 50 x 10 cm spacing, but conversely for grain yield, revealing that although wider spacing increased mean values of these characters as response to declining competition, the values might not compensate decreasing population density, resulting in the lower grain yield. In closer spacing, increasing 57 % of higher grain yield was obtained in comparing with wider spacing. Similar results were reported in pearl millet (W'Khaitir and Vanderlip, 1992) and in soybean (Board et a1., 1996). However, different from these results, no significant effect of population density on pearl millet grain yield (M'Khaitir and Vanderlip, 1992) and rice (Gravois and Helms, 1992) were reported.

No Significant difference for panicle length and grain weight per panicle by differing spacing revealed that the close spacing was not unfavorable to these yield components.

No significant effect of the low temperature germination on the field performance revealed that the genotypes adapted to early spring planting might have no adverse effects to yield and yield components. In case of earlier planting, genotypes selected for low temperature might give higher yield.

Interrelationship among characters in pearl millet, reported in the previously chapter, showed that number of productive panicles, number of productive tillers, panicle length and grain weight per panicle had high correlation to grain yield. However, as the number of productive tillers really showed a negative direct effect to grain yield, by negative value of path coefficient, the number of productive tillers was not included in this study. The significant S x E interaction may become more important, since selection for a genotype, exhibiting superior performance under a specific environment condition, is possible.

The significant S x E interaction leads to another consideration that selection for a superior genotype should be conducted in the specific environment. Significant effect of S x SP interaction on number of productive panicles and panicle weight requires separate selections by these characters for genotypes adapted for narrow or wide spacing. S x T interaction on panicle weight and grain weight per panicle requires separate selections by these characters for genotypes adapted for spring or fall sowing.

No S x SP interaction effect on panicle length and grain weight per panicle leads to the considering of the stability of these characters in different spacing. No S x T interaction effect on number of productive panicles and panicle length also suggests the stability of this character in different season sowing.

The phenotypic correlations and genetic correlations of number of productive panicles, panicle weight and grain weight per panicle to grain yield were calculated, and the values of genetic gain were estimated in the previously chapter. All the facts confirmed that panicle length had high stability. Whereas, number of productive panicles, panicle weight and grain weight per panicle might be considered as selection criteria for high grain yield in a specific environment. In conclusion, fall sowing showed grain yield of 224~309 g m² though it was lower in spring sowing. Closer spacing increased grain yield. S x T, S x SP interactions were observed for several characters. Among characters studied, panicle length might be considered as a stable character, whereas number of productive panicles, panicle weight and grain weight per panicle might be favorable as selection criteria for high grain yield genotypes in a specific environment. No effect of low temperature pretreatment during germination led to the suggestion that pearl millet genotypes selected for low temperature might have no adverse effects on grain yield and yield components.

IV. RESPONSE TO LOW TEMPERATURE STRESS AND PHOTOPERIOD SENSITIVITY

1. Response to Early Spring Plating in Several Genotypes

Introduction

As different planting dates might result in different photoperiod and temperature regimes, which might affect both growth and yield or yield components, selected genotypes could be affected by their responses to the planting date. M'Khaitir and Vanderlip (1992) reported that pearl millet showed no significant response to different planting date of May, June and July in Manhattan and St. John, KS, on 1988 and 1989. However, the genotype x sowing interaction in Manhattan 1989 was significant for the yield. Yoshida and Sumida (1996) applied mass selection for germination at a low temperature, heavy grain weight and early heading in a pearl millet population and estimated the heritability of these characters. However, the performance and grain yield of the genotypes sown at early spring are not yet evaluated. An understanding of the response of genotypes to different planting date might facilitate developing pearl millet cultivars adapted for early spring planting.

In this section, growth and grain yield response of seven genotypes on different planting date was studied in relation to obtaining high grain yield genotypes for early spring planting.

Materials and methods

As selected genotypes (G) from previous studies i.e., genotype selected for yield (G1), grain weight (G2), number of productive panicles (G3), panicle weight (G4), shoot length (G5), and root length (G6), and the original open pollinated short population "ICMV89074" from ICRISAT, India (G7) were subjected to materials. Planting date of 29 April, 6 May, 13 May and 20 May, as date of transplanting of 3 weeks old seedling from greenhouse to the field, were arranged for treatment. To prepare the seedlings, seeds were germinated on a filter paper for 3 days and then sown in ziffy paper pots, with 2 plants each, in a greenhouse for 3 weeks. Each genotype was planted in a plot consisting of three rows, with 10 plants each, at 10 and 40 cm interval within and between rows respectively, and 0.8 g N, 0.8 g P₂O₅, and 0.8 g K₂O per m² were applied. Leaf area and dry weight, of leaves, stem, and root were measured at 2,3,5 and 6 weeks after transplanting from the plants in the center row. For yield and yield components observation, 3 plants were sampled from each row. Data were subjected to analysis of variance continued by protected LSD test (Steel and Torrie, 1980) using IRRISTAT 3/93.

Results

Daily mean air temperature during growing period fluctuated from the 13.1 °C (minimum) to the 31.3 °C (maximum) with 22.8 °C in average. Daily mean precipitation fluctuated from the 0 mm (minimum) to the 117.0 mm (maximum) with 8.9 mm in average. The fluctuation in mean air temperature and precipitation in every ten days during growing period was shown in Fig. 9.



Fig. 9. Fluctuation in mean air temperature and mean precipitation in every ten
days from April to August 1997 in Fukuoka (Source: Fukuoka District Meteorological
Observatory) □ temperature ◆ precipitation

Table 29. Mean squares by ANOVA for leaf area (LA), dry weight of leaves (LDW), stem (SDW) and root (RDW) in different planting date.

Source	df	LA (100 cm ²)	LDW (g)	SDW (g)	RDW (g)
Treatment	27	95.0**	20.5**	184.2**	3.6**
Genotype (G)	6	59.0	5.6	178.5*	2.2
Planting date (D)	3	339.0**	98.6**	755.8**	17.4**
G x D	18	66.0**	12.5	90.8	1.8

*, **; significant at 5 and 1% level, respectively.
Table 29 shows the analysis of variance for growth responses on different genotypes and planting date. Tables 30 and 31 show the mean values of genotypes for growth characters in different planting dates and Table 32 shows the mean values for growth characters across genotypes.

(1) Growth responses

Effect of planting date was significant for all growth characters. However, no significant effect of genotypes was observed except for stem dry weight (Table 29). Interaction effect of genotype x planting date was detected only for leaf area.

Across genotypes, leaf area (LA) and total dry weight (leaf, stem and root dry weight) on 29 April was lower than on 6 May until 5 week after transplanting (WAT). However, the mean value of LA, dry weight of leaves (LDW), stem (SDW) and root (RDW) between 29 April and 6 May were not significantly different on 6 WAT (Figs. 10 and 11, Table 32). The genotypes showed similar pattern in the growth on each planting date (Fig. 12) and the selected genotypes, G1~ G6, performed relatively higher than the original, G7, in their mean values for LA, LDW, SDW and RDW (Tables 30 and 31).

(2) Yield and yield components responses

Analysis of variance for yield and yield components was shown in Table 33. Effect of genotypes was significant for number of productive panicles (PP), panicle length (PL), panicle weight (PW), and yield per plant (Y), but not significant for plant height (PH). Table 30. Mean values for leaf area (LA) and leaves dry weight (LDW) of genotypes in different planting date.

Genotypes	LA (1000 cm^2 per plant)				LDW (g per plant)			
	29 Apri1	6 May	13 May	20 May	29 April	6 May	13 May	20.May
G1	1.5 b	2.1 a	1.7 abc	1.2 a	5.3 а	8.0 ab	6.7 ab	4.0 a
G2	1.0 b	1.7 a	1.1 bed	1.0 a	5.0 a	10.0 ab	3.0 bc	4.0 a
G3	3.1 a	2.0 a	1.1 bed	1.0 a	7.3 a	8.7 ab	4.3 abc	4.7 a
G4	1.1 b	2.0 a	2.0 ab	1.0 a	3.0 a	11.7 a	7.7 ab	3.7a
G5	1.9 b	2.1 a	1.0 cd	0.9 a	5.0 a	8.7 ab	3.3 bc	3.7 a
G6	1.6 b	1.7 a	2.2 a	0.9 a	4.3 a	5.0 b	9.0 a	3.7a
$\mathbf{G7}$	1.5 b	1.7 a	0.7 d	0.8 a	5.0 a	9.3 ab	1.0 c	2.7a

G1; sel. for yield, G2; sel. for seed wt. per panicle, G3; sel. for prod. panicles, G4; sel. for mean panicle wt., G5; sel. for shoot length, G6; sel. for root length and G7; original pop. For each factor, means followed by a common letter in a column are not significantly different at 5% level according to ANOVA protected LSD test.

Genotypes	SDW (g per plant)				RDW (g per plant)			
	29 Apri 1	6 May 1	3 May	20 May	29 April	6 May	13 May	20 May
G1	16.3 a	16.7 b	7.3 a	4.0 a	2.0 a	2.0 a	3.0 ab	1.3 a
G2	6.7 a	21.7 ab	2.0 a	5.7 a	1.3 a	2.7 ab	2.0 bc	1.3 a
G3	12.7 a	35.3 a	7.3 a	10.0 a	2.0 a	3.3 ab	1.7 bc	1.7 a
G4	5.3 a	27.7 ab	13.3 a	5.0 a	0.7 a	4.0 ab	4.7 a	1.0 a
G5	8.7 a	7.0 c	4.3 a	4.3 a	1.7 a	2.7 ab	1.7 bc	1.0 a
G6	12.3 a	12.3 c	10.3 a	3.0 a	1.0 a	4.0 a	3.0 ab	1.0 a
$\mathbf{G7}$	9.0 a	8.0c	1.3 a	2.3 .a	1.0 a	2.7 ab	1.0 c	0.3 a

Table 31. Mean values for stem (SDW) and root (RDW) dry weight of genotypes in different planting date.

For each factor, means followed by a common letter in a column are not significantly different at 5 % level according to ANOVA protected LSD test. For G1-G7, see Table 30.



Fig. 10. Differences for leaf area growth of genotypes between planting date of 29 April (a) and 6 May (b). WAT; week after transplanting. G1-G7; genotype selected for grain yield per plant, grain weight per panicle, no. of prod. panicles, panicle weight, shoot length, root length and the original population.



Fig. 11. Differences for total dry weight production of genotypes between planting date of 29 April (a) and 6 May (b). WAT; week alter transplanting. G1 - G7.. see Fig. 10.



Fig. 12. Differences for leaf area (a) and total dry weight (b) across genotypes in different planting date. WAT; week after transplanting.

Table 32. Mean values across genotypes for leaf area (LA), dry weight of leaves (LDW), stem (SDW) and root (RDW) in different planting date.

Planting date	LA (1000 cm2)	LDW (g)	SDW (g)	RDW (g)
29 April	1.7 ab	5.1 b	10.1 b	1.4 c
6 May	1.9 a	8.8 a	18.4 a	3.0 b
13 May	1.4 b	$5.0 \mathrm{b}$	6.6 bc	2.4 b
20 May	1.0 c	3.8 b	4.9 c	1.1 c

For each factor, means followed by a common letter in a column are not significantly different at 5% level according to ANOVA protected LSD test.

Source	df	Plant height (100 cm)	No. of prod. panicles	Panicle lengt (cm)	h Panicle weight per plant (100g)	Grain yield per plant (10g)
Treatment	27	1.5*	0.5 **	11.2 **	3.0*	18.9 **
Genotype (G)	6	1.2	1.3 **	31.2 **	10.0 **	55.0 **
Planting date (D)	3	6.4 **	0.5 **	12.1 *	3.1	12.6
G x D	18	0.9	0.2	4.4	0.6	7.9

Table 33. Mean squares by ANOVA for yield and its components in different planting date.

*,**; significant at 5 and 1% level, respectively.

No significant effect of planting date for panicle weight and yield was observed and no significant genotype x planting date interaction was detected for all characters.

The mean values for yield and yield components on different planting date were shown in Tables 34 and 35. The mean values of G1, G3 and G4 were relatively higher than those of other genotypes for yield and yield components. Especially grain yield of G3 on 29 April showed superior value, followed by G1 and G4 (Table 35).

Across genotypes, the mean values for yield and yield components were comparable at different planting date (Table 36). In almost all cases, the mean values for yield and yield components were not significantly different each others.

Discussions

Low temperature effects on the germination characters and relationship between the germination characters and yield components in the field were discussed in previous chapters. In this section, it is revealed that effect of planting date was significant for all characters, but effect of genotypes was significant only for stem dry weight, showing that effect of planting date was larger than that of genotypes for the growth characters.

Mean temperature in the last ten days of April planting date was low as 16.3 °C. This condition resulted in the inhibiting of the growth especially in the early stages until 5 week after transplanting (Fig. 10a) for all genotypes. However, rapid growth in the later stages resulted in the non-significant difference between the mean values of growth characters on 29 April and the values in later planting dates on 6 WAT (Table 32, Figs. 9, 10 and 11).

Genotypes	No. of prod. panicles				Panicle length (cm)				
	29 Ajpril	6 May	13 May	20 May	29 April	6 May 1	.3 May	20 May	
G1	2.7 ab	2.0 a	1.9 b	2.4 ab	22.5 abc	21.9 ab	22.0 ab	23.5 ab	
G2	2.0 c	1.9 a	2.0 b	2.2 b	23.0 abc	20.6 ab	20.1 bc	21.2 abc	
G3	3.4 a	2.2 a	3.2 a	3.0 a	25.6 a	21.7 ab	25.5 a	21.4 abc	
G4	2.3 bc	1.7 a	2.2 b	$2.3 \mathrm{b}$	22.7 abc	23.7 a	23.3 ab	24.3 a	
G5	1.8 c	2.0 a	1.9 b	1.7 b	19.1 c	18.0 b	17.8 c	20.5 abc	
G6	1.8 c	1.7 a	2.4 b	1.7 b	21.2 bc	17.9 b	17.4 c	18.8 c	
G7	1.8 c	1.5 a	2.2 b	1.7 b	24.4 ab	21.1 ab	18.1 c	19.7 bc	

Table 34. Mean values fTor no. of prod. panicles and panicle length of genotypes in different planting date.

For each factor, means followed by a common letter in a column are not significantly different at 5% level according to ANOVA protected LSD test. For G1-G7, see Table 30.

Genotypes	Pan	Panicle weight per plant (g)			Grain yield per plant (g)		
	29 April	6 May	13 May	20 May	29 April 6	3 May 1	13 May 20 May
G1	36.9 ab	36.1 a	39.0 ab	38.7 a	23.5 b	15.6 a	16.1 a 24.0 b
G2	39.7 ab	46.5 a	51.5 ab	29.4 a	15.6 bc	18.8 a	23.3 a 18.7 b
G3	59.9 a	43.5 a	63.2 a	44.2 a	50.5 a	18.6 a	22.1 a 41.1 a
G4	57.3 ab	39.3 a	48.5 ab	45.6 a	16.5 bc	13.9 a	19.3 a 25.4 b
G5	27.3 b	33.8 a	30.0 b	18.2 a	9.2 bc	10.8 a	11.1 a 10.7 b
$\mathbf{G6}$	26.9 b	22.9 a	25.7 b	19.5 a	12.8 bc	8.7 a	9.2 a 12.8 b
G7	29.3 ab	29.7 a	30.3 b	18.9 a	5.2 c	10.5 a	10.4 a 10.9 b

Table 35. Mean values for panicle weight and grain yield of genotypes in different planting date.

For each factor, means followed by a common letter in a column are not significantly different at 5% level according to ANOVA protected LSD test. For G1-G7, see Table 30.

Planting date	Plant height (cm)	No. of prod. panicles	Panicle length (cm)	Panicle weight per plant (g)	Grain yield per plant (g)
29 April	106.3 a	2.24 a	22.6 a	39.6 a	19.0 ab
6 May	101.8 a	1.87 b	20.7 b	35.9 a	13.8 b
13 May	117.8 b	2.23 a	20.6 b	41.2 a	15.9 ab
20 May	108.2 a	2.12 a	21.3 b	30.6 a	20.5 a

Table 36. Mean values for yield and its components across genotypes in different planting date.

For each factor, means followed by a common letter in a column are not significantly different at 5% level according to ANOVA protected LSD test. For G1-G7, see Table 30.

On the other hand, the genotypes showed similar growth in each of planting date and only stem dry weight differed among genotypes. It appears that the growth characters response to the different planting date was more significant than to the different genotypes.

The higher mean value of leaf area of G3 on 29 April but not significant in another planting date and higher mean value of G4 on 13 May contributed to the genotype x planting date interaction. However, no significant G x D interaction for almost all characters revealed that there were no changes in magnitude of the growth response of genotypes to the different planting date. An understanding of the environmental stability of genotypes helps in determination of their suitability for the fluctuations in growing conditions that are likely to be encountered (Fehr, 1987b). Results of this study suggested the growth stability of genotypes in the different planting date.

The significant effect of genotypes for all yield and yield components, except plant height, and not significant effect of planting date for panicle weight and yield in this study revealed that yield and yield components were less influenced by planting date.

Furthermore, differences among genotypes suggested the effective selection conducted previously.

The non significant G x D interaction for all yield and yield components revealed that there were no changes in the magnitude of the response in genotypes on different planting date. This leads to suggestion of yield and yield components stability in genotypes and adaptation for early spring planting. The higher mean value of G1, G3 and G4 than other genotypes for yield components revealed the more stable and higher grain yield potential of these genotypes for early spring planting. Superiority of G3 on 29 April for grain yield suggested that the selection for number of productive panicles might increase the grain yield and adaptability of pearl millet for early spring planting.

In conclusion, early spring planting inhibited growth of genotypes at early stage, but not significantly at the later stage. Significant growth response of genotypes was caused mainly by the different planting date. Significant yield and yield components response was caused by the difference of genotypes. No significant G x D interaction for growth, yield and yield components, except for leaf area was observed. Genotypes selected for yield (G1), number of productive panicles (G3) and panicle weight (G4) were relatively stable in different planting date and might be considered as genotypes adapted for early spring planting.

2. Response of Pearl Millet to the Different Photoperiod

Introduction

The geographical area in which a crop is productive can be limited by the day length required for flower initiation. Knowledges of photoperiod sensitivities enable breeders to select for increased adaptability of cultivars to various latitudes (Fehr, 1987a).

Many researches were conducted to study the photoperiod sensitivity of crops such as wheat (Miglietta, 1989., Slafer and Rawson, 1995, 1996; Slafer et al., 1995; Brooking et al., 1995; Hotsonyame and Hunt, 1997), sorghum (Muchow and Carberry. 1990), triticale (Ewert, 1996), common bean (White and Laing, 1989), peanut (Bagnall and King, 1991a,b), groundnut (Linnemann, 1991; Linnemann et al., 1995), pigeonpea (Omanga et al., 1995) and brassica spp. (Nanda et al., 1996) using various characters.

Photoperiod sensitivity in pearl millet is a well recognized trait (Anand Kumar and Andrews, 1993). Most of landraces and lines are photoperiod sensitive (Burton, 1981). The crop capables for flowering at all photoperiods, though much earlier with short days (Begg and Burton, 1971) and delay in extended day length (Bidinger and Rai, 1989). Bhardwaj and Webster (1971) reported a high degree of dominance for earlyness.

Depending on genotypes, pearl millet might be classified as: 1) Relatively day neutral, being able to flower irrespectively of day length; 2) Short day, head only when the days are short; and 3) Facultative short day, head under long days but much earlier under short days (reviewed from Anand Kumar and Andrews, 1993). In addition, Bhardwaj and Webster (1971) reported the possibility to develop high-yielding, day-length neutral, and day-length sensitive genotypes and Burton (1981) reported the possibility of developing photoperiod insensitive genotypes. However, studies on photoperiod sensitivity for growth characters and yield components in pearl millet which is different in their seedling age of transplanting date are scarce.

Objectives of this experiment are 1 to study the sensitivity of pearl millet exposed in three different photoperiod conditions and 2 to study if the sensitivity is influenced by different seedling age.

Materials and Methods

Three and four week-old seedlings of a high grain yielding short statured genotype were used as materials. Experiment was arranged in a randomized complete block design with 3 replications.

Seeds were sown in ziffy paper pots filled with soil at 9 and 6 June 1997 and placed in a greenhouse to prepare the 4 and 3 weeks seedlings. Seedlings were transplanted to plastic pots filled with about 4 kg sifted soil, 0.8 g N, 0.8 g P_2O_5 and 0.8 g K_2O per pot, then were exposed in three different adjustable photoperiod chambers at 9 July. Photoperiod was adjusted for 8, 12 and 16 h. Three seedlings per pot were planted, and one plot consisted of 3 pots. Therefore, there were 6 pots with 9 plants included in each chamber, with spacing of 25 cm between pots.

Upper part dry weight, 50% heading (as days from germination to 50% heading), grain filling period and harvest index were observed using average 3 plants. Number of productive panicles, panicle length, panicle weight, grain weight per panicle and grain yield per plant as yield components were observed using average 3 plants. Sensitivity was shown by significant effect of photoperiod, whereas changes of the response to photoperiod obtained by different seedling age was shown by significant photoperiod x seedling age interaction in ANOVA.

Results

Table 37 shows ANOVA for growth characters and Table 38 shows ANOVA for yield components as response to different photoperiod and seedling age. Mean values for all 9 characters are presented in Tables 39 and 40.

Upper part dry weight, 50% heading, grain filling periods, harvest index, grain weight per panicle and grain yield per plant were significantly influenced by photoperiod (Tables 37 and 38). Seedling age affected 50% heading, harvest index and grain weight per panicle. Photoperiod x seedling age interaction was significant for 50% heading, harvest index and grain weight per panicle. No significant difference as responses to photoperiods was observed for number of productive panicles, panicle length and panicle weight. In addition, no significant difference also was observed between seedling age for upper part dry weight, grain filling period, number of productive panicles, panicle length, panicle weight and grain yield per plant.

In 8 h days, upper part dry weight, grain filling period, harvest index and all yield components were not significantly different from the values in 12 h days.

Table 37. Mean squares by ANOVA for plant dry weight, 50% heading, seed filling period and harvest index of pearl millet in different photoperiod.

Source	df	Upper part dry weight (100 g)	50% heading (10 days)	Seed filling periods (10 days)	Harvest index (%)
Treatment	5	10.37*	14.61**	13.5**	4.82**
Photo period (P)	2	19.48*	35.4**	29.8**	10.62**
Seedling age (S)	1	5.27	1.6*	0.14	16.01*
P x S	2	3.79	3.6	3.77*	0.63

*,**; significant at 5 and 1% level, respectively.

Source	df	No.of prod. paniles	Panicle length (cm)	Panicle weight (g)	Grain weight per panicle(g)	Grain yield per plant (g)
Treatment	5	0.06	24.8	4.78	8.12**	47.2*
Photoperiod (P)	2	0.06	0.4	9.69	12.06**	96.3*
Seedling age (S)	1	0.89	56.9	2.88	3.74*	8.8
P x S	2	0.06	34.1	1.07	4.97**	16.0

Table.38. Mean squares by ANOVA for yield components of pearl millet in different photoperiod.

*,**; significant at 5 and 1% level, respectively.

However, upper part dry weight and grain filling period both in 8 and 12 h days were lower than of 16 h days. In contrast, harvest index, grain weight per panicle and grain yield per plant both in 8 and 12 h days were higher compared to 12 h days (Tables 39 and 40).

Upper part dry weight increased 191% and grain filling period was prolonged 10 days with 16 h days. Conversely, harvest index decreased 78 %, grain weight per panicle decreased 28 % and grain yield decreased 37 % with 16 h days.

Fifty % heading was influenced by photoperiod. The earlier heading in 8 h days than both in 12 and 16 h days, and earlier heading in 12 h than in 16 h days were observed (Table 39). Fifty % heading was 15 days earlier with 8 h days and prolonged 10 days with 16 h days.

Four week seedlings showed lower values for 50% heading, harvest index and grain weight per panicle than three week seedling, regardless of photoperiods (Tables 39 and 40).

No significant difference was observed for number of productive panicles, panicle length and panicle weight both in all photoperiods and in different seedling age.

I **Discussions**

As upper part dry weight, 50% heading, grain filling period, harvest index, grain weight per panicle and grain yield per plant were significantly influenced by photoperiod, these characters appeared to be sensitive to day length. Table 39. Mean values for upper.part dry weight, 50% heading, seed filling period and harvest index of pearl millet in different photoperiod.

Upper part dry weight (g)	50% heading (days)	Seed filling periods (10 days)	Harvest index (%)
21.6 b	62.8 c	27.2 b	83.9 a
17.3 b	67.5 b	31.7 b	103.4 a
50.4 a	77.8 a	41.0 a	22.8 b
eeks)			
24.4 a	70.3 a	33.0 a	79.4 a
35.2 a	68.4 b	33.6 a	60.6 b
	Upper part dry weight (g) 21.6 b 17.3 b 50.4 a eeeks) 24.4 a 35.2 a	Upper part 50% heading dry weight (g) (days) 21.6 b 62.8 c 17.3 b 67.5 b 50.4 a 77.8 a eeks) 24.4 a 70.3 a 35.2 a 68.4 b	Upper part 50% heading Seed filling periods dry weight (g) (days) (10 days) 21.6 b 62.8 c 27.2 b 17.3 b 67.5 b 31.7 b 50.4 a 77.8 a 41.0 a eeks) 24.4 a 70.3 a 33.0 a 35.2 a 68.4 b 33.6 a

For each factor, means followed by a common letter in a column are not significantly different at 5 % level according to ANOVA protected LSD test.

. No. of prod. panicles	Panicle length (cm)	Panicle weight (g)	Grain weight per panicle (g)	Grain.yield per plant (g)
)				
2.2 a	21.2 a	15.7 a	8.2 a	17.9 a
2.2 a	21.5 a	16.8 a	7.6 a	16.3 ab
2.0 a	21.0 a	14.3 a	5.5 b	10.3 b
veeks)				
2.3 a	23.0 a	15.2 a	6.6 a	15.6 a
1.9 a	19.4 a	16.0 a	7.6 b	14.2 a
	. No. of prod. panicles 2.2 a 2.2 a 2.0 a veeks) 2.3 a 1.9 a	. No. of prod. Panicle panicles length (cm) 2.2 a 21.2 a 2.2 a 21.5 a 2.0 a 21.0 a veeks) 2.3 a 23.0 a 1.9 a 19.4 a	No. of prod. Panicle Panicle panicles length (cm) weight (g) 2.2 a 21.2 a 15.7 a 2.2 a 21.5 a 16.8 a 2.0 a 21.0 a 14.3 a veeks) 2.3 a 23.0 a 15.2 a 1.9 a 19.4 a 16.0 a	. No. of prod. Panicle Panicle Grain weight panicles length (cm) weight (g) per panicle (g) 2.2 a 21.2 a 15.7 a 8.2 a 2.2 a 21.5 a 16.8 a 7.6 a 2.0 a 21.0 a 14.3 a 5.5 b veeks) 2.3 a 23.0 a 15.2 a 6.6 a 1.9 a 19.4 a 16.0 a 7.6 b

Table 40. Mean values for yield components of pearl millet in different photoperiod.

For each factor, means followed by a common letter in a column are not significantly different at 5 % level according to ANOVA protected LSD test.

Earlier heading in 8 h days than both in 12 and 16 h days, and earlier heading in 12 h than in 16 h days revealed that the genotypes studied can flower in any day length, however the time was earlier in a shorter photoperiod. This finding accords with Begg and Burton (1971), Bidinger and Rai (1989) in pearl millet and Slaifer and Rawson (1995) in wheat.

As upper part dry weight, grain filling period, harvest index, and all yield components were not significantly different in 8 and 12 h days, these characters may be insensitive to 8 and 12 h days. However, the sensitivity to 16 h days was expressed for these characters. The 16 h days increased the values of upper part dry weight and grain filling period, but decreased the values of harvest index, grain weight per panicle and grain yield per plant (Tables 39 and 40). On the contrary, Slafer et al. (1995) reported the increase in number of leaf primordia and number of elongated internodes in wheat, and Bagnall and King (1991a and 1991b) reported an enhancing of flower production and pod number in peanut with short photoperiod.

The significant photoperiod x seedling age (P x S) interaction for 50% heading, harvest index and grain weight per panicle, indicated that the response to photoperiod was not the same for these characters in different seedling age.

Earlier heading of 4 week seedling than 3 week seedling in 16 h days but not different both in 8 and 12 h days, led to P x S interaction for 50% heading (Fig. 13a).



Fig. 13. Changes in 50% heading (a), seed filling period (b) and grain weight (c) in different seedling ages and photoperiods.

In addition, P x S interaction for grain filling period was contributed by the shorter grain filling period of 3 week seedlings than 4 week seedlings with 8 h days but in contrary for both with 12 and 16 h days (Fig. 13b). Furthermore, the lower grain weight of 3 week seedlings than 4 week seedlings with 16 h days, but not significant for both with 8 and 12 h days, caused significant P x S interaction for grain weight per panicle (Fig. 13c). The significant P x S interaction also revealed that photoperiod sensitivity for 50% heading, grain filling period and grain weight per panicle was influenced by seedling age.

The lower values of harvest index and grain weight per panicle with 4 week seedling compared with 3 week seedling regardless of photoperiods confirmed the suitability of 3 week seedling for transplanting.

No significant difference for number of productive panicles, panicle length and panicle weight both in all photoperiod and in different seedling age indicated the insensitivity and stability of these characters to both 8 and 16 h days even by 3 or 4 weeks seedling. Hotsonyame and Hunt (1997) reported that rate of leaf appearance in wheat was not influenced by photoperiod. Apparently, growth characters were more sensitive to photoperiod than yield components in pearl millet.

In conclusion, upper part dry weight, 50% heading, grain filling period, harvest index, grain weight per panicle and grain yield per plant were sensitive characters to photoperiod. The 16 h days increased growth characters as plant dry weight, heading date and grain filling period, but decreased yield characters as harvest index, grain weight per panicle and grain yield per plant. Number of productive panicles, panicle length and panicle weight were relatively insensitive characters to photoperiod. There was a contribution of seedling age on the photoperiod sensitivity for 50% heading, harvest index and grain weight per panicle. In this study, as pearl millet can flower under 16 h days but much earlier under 8 h days, it was confirmed to be a facultative short-day plant.

V. CROP PROPAGATION THROUGH MATURE

INFLORESCENCE CULTURE

Introduction

In vitro crop propagation may be useful to propagate genetically identical genotypes rapidly. Plant regeneration from cultured immature inflorescence in buckwheat (Takahata, 1988), sorghum (Cai and Butler, 1990; Wen et al.1991; Nakamura et al. 1997) and rye (Rakoczy-Trojanowska and Malepszy, 1993) were reported. Bajaj and Gupta (1992) studied in vitro regeneration and somaclonal variation for salt tolerance using young unopened inflorescence of Indian pearl millet cultivar.

In this section, culture of immature inflorescences from two selected genotypes was carried out for developing a crop propagation procedure asexually in the genotypes.

Materials and methods

Two selected genotypes, selected for high grain yield per plant (G1) and for high grain weight per panicle (G2), were used as materials. Three weeks old seedlings of genotypes were transplanted to pots filled with 4 kg soil and 0.8 g N, 0.8 g P_2O_5 and 0.8 g K₂O per pot in a greenhouse on 9 July 1997 to prepare materials for culturing. The immature inflorescences (about 2-9 cm long of unopened panicle) with the leaf sheath were collected on 3 - 10 July 1997. Alter the outer leaves surrounding the inflorescence were carefully removed, the inflorescences were surface disinfected by dipping in 70% ethanol for 30 see. and washed three times with sterile distilled water in a laminar now chamber. Inflorescences were cut into 2-3 mm-long segments and cultured on MS basal medium (Murashige and Skoog, 1962) supplemented with 2,4-D

(2.5 mg L⁻¹), LAA (1.0 mg L⁻¹) and kinetin (2.0 mg L⁻¹). Sucrose and gellan gum were supplemented at 2% and 1500 mg L⁻¹, respectively. The pH of the medium was adjusted to 5.8 prior to autoclaving (121 °C for 15 min). The cultures were incubated in two different degree of temperature, 25 °C and 30 °C. At least 20 inflorescences were cultured on each medium. Frequency of calli was calculated as follow:

For regeneration of plantlets, after 4 weeks from culture, calli were transplanted on a MS basal medium supplemented with IAA (3.0 mg L^{-1}) and kinetin (2.5 mg L^{-1}), and incubated at 25 °C. Frequency of shoot and root initiated was calculated as follow:

	no. of calli initiating shoot or root	
Freq. shoot or root initiation =		x 100 %
	total no. ca11i transplanted	

The chromosome number was counted in the root tip cells from germinated seeds and regenerated plantlets according to Hinata (1990).

Results

1. Callus initiation

Genotype	Culturing date	Freq. of callus formation (%)*		Mean
		25 C	30 C	
G1	3 July	81.8	82.5	82.1
	10 July	70.0	70.0	70.0
Mean		75.9	76.2	76.1
G2	3 July	43.5	46.8	46.1
	10 July	73.0	45.0	59.0
Mean		59.2	45.9	52.6

x100%

Table 41. Frequency of callus formation from pearl millet immature inflorescence after 4 weeks of culture.

* No. of calli obtained

No. of inflorescences cultured

Callus initiation was observed in some cultures from 4 days after inoculation, which agreed with the observation by Pius et a1 (1993). Segments became swollen, and translucent callus initiated from the peripheral region of transversely cut segments. However, almost all cultures formed callus about 3 weeks after inoculation. This callus consisted of compact and soft friable tissue. The compact nodular callus proliferated rapidly at about 4 weeks after inoculation. A faster growth of callus masses at 30 than 25 °C was observed. Frequency of callus formation of the two genotypes in different temperature was presented in Table 41. The frequency in average was 76.1 and 52.5 % for G1 and G2, respectively. G1 showed a similar response to different temperature for the frequency of callusing (76.2 % at 30 °C; 75.9 % at 25 °C), whereas G2 showed a little higher for callusing at 25 than 30 °C (59.0 % at 25 °C; 45.9 % at 30°C).

2. Plantlets regeneration

The compact fast-growing callus was grown in a regeneration medium for plantlets induction. After 4 days, Compact white sectors of embryonic callus appeared on light creamy callus. The embryonic areas and embryos, which then developed on the surface of the callus, later turned green. Root and shoot initiation started from these calli after 7 days of subculturing. Young plantlets developed a good shoot and root system on the regenerated medium. Frequency of shoot formation originated from calli inducted at 25 °C was same as; 80 % in G1 and G2, and frequency of root formation was 45 % (G1) and 35 % (G2).



Fig. 14. Establishment of immature inflorescence culture and plantlet regeration in pearl millet.

A; four-weeks-old calli of segment of immature inflorescence culture, B; formation of shoots and roots in eight-week-old calli derived plantlet, C; seven-days-old plantlets after transferring to paper pot containing sterile soil, D; whole plant after established in the pot, A and F; chromosome numbers as 2n = 14 in root tip cell from original and plantlet regenerated materials.

However, very low in frequency of shoot and root was formed from calli inducted at 30 °C (20% for G1 and 10 % for G2).

After about 2 months of subculture, plantlets were transferred to ziffy pots filled with soil adjusted well in a 25 °C incubator for acclimatization. The plantlets continued further growth well.

From the root tip cells of plantlets induced and germinated seed, the chromosome number was counted. No variation in chromosome number in root tip cells of germinated seeds was observed. The chromosome number as 14 was observed. Chromosome number in root tip cells of plantlets was 14.

Discussions

In open pollinated crops, it is difficult to maintain the genotype stability through grains propagation. In vitro culture is aimed primarily to a rapid propagation of superior genotypes which are identical to the source material (Borojevic, 1990).

Growth stage of plant material is one of the important factors influencing the success of culture. Young and soft tissues are generally more amenable for culture than older woody tissues (Pierik, 1987). The growth stage of immature inflorescences in this study, about 2-9 cm long of unopened panicle, was suitable as a high callus formation and plantlets regeneration was obtained. Bajaj and Gupta (1992) reported that very young and too old segments from inflorescence pearl millet did not form callus, or they died.

G1 had a similar response for callusing in different temperature, whereas G2 showed a different response where 25 °C was more favorable. This revealed that temperature might, varying with genotypes, influence the callus formation and the temperature as 25 °C was favorable for the genotypes.

Both genotypes showed a high and comparable number of plantlets from calli formed at 25 °C. But, a little number of plantlets from calli formed at 30 °C was observed in both genotypes. This revealed that temperature effect of culturing continued until the subculturing. Furthermore, temperature as 25 °C was favorable for callus formation and plantlets induction.

As the plantlets grow well after transferred to soil medium, the procedure practiced in this study was effective.

The chromosome number as 14 originated from root tip cells of germinated seed and of plantlets was observed. Its meant that chromosome number in both cells of plantlets propagated through immature inflorescence culture and of the original material was same and the plant regeneration procedure practiced in this study had a possibility to be used for rapid crop propagation of genetically identical materials.

In conclusion, the results obtained show that plantlets were induced from the immature inflorescences of selected genotypes through calli. Temperature of 25 °C was favorable for callus formation and plantlets regeneration. Chromosome number as 2n=14 was confirmed in root tip cells originated from both germinated seeds and regenerated plantlets. The plant regeneration procedure practiced in this study had a possibility to be used for rapid crop propagation of genetically identical materials.

VI. CONCLUSIONS

This thesis mentioned several basic studies in selection for grain yield population improvement and some aspects of environment in relation to the interaction and stability in pearl millet. Effective crop propagation through immature innorescence culture was also revealed.

In this study, pearl millet showed wide variability for the agronomic characters. Phenotypic correlations and genetic correlations study revealed that some characters showed close relationship to grain yield. Number of productive panicles, panicle weight and grain yield per panicle were highly correlated and important characters to grain yield.

The effective recurrent selection procedure was established in this study. Selection for yield and each yield component improved each characters by 73 to 187 %. Indirect selection through yield components clearly increased grain yield. The recurrent selection was effective for increasing both selected and non selected characters. Grain weight per panicle, panicle weight and number of productive panicles showed high heritability and high genetic correlation to grain yield. As the very close relationships; between yield components and grain yield were identified, selection for higher grain yield through the yield components was suggested. Percentage increasing of grain yield with direct selection (236 %) and indirect selection through the yield components (113-216 %) was observed. Considering the non significantly different grain yield values among genotypes selected for grain yield and for its components, effectiveness of direct selection and indirect selection through yield components was comparable for improving grain yield.

The studies found that lower temperature declined grain germination characters and genotypes gave same response to temperature levels in the linear pattern. Temperature had more contribution than genotype to the germination characters. Plants in the field may have a recoverability after 15 °C temperature germination pretreatment.

Selection procedure for seedling characters under a low temperature condition was developed. A fairly large values of genetic gain of the seedling characters were obtained. Selection had a significant effect on seedling characters at a low temperature. Selection for longer shoot or root increased % germination at a low temperature, panicle length and panicle weight in a field in addition to shoot and root length. Shoot and root length had high heritability and may be useful as selection criteria at a low temperature. Considerable genetic gain for seedling characters should be possible, especially for a longer shoot and root length.

In general, plant performance was influenced by genotype, environment and the interaction of them. Studies found that fall season sowing showed grain yield of 224~309 g m⁻² though it was lower in spring sowing. Closer spacing increased grain yield. Genotype x season and genotype x spacing interaction were observed for several characters. Panicle length might be considered as a stable character, whereas number of productive panicles, panicle weight and grain weight per panicle might be favorable as selection criteria for high grain yield genotypes in a specific environment. Pearl

millet might be considered as an early spring and late summer sowing grain crop.

Genotypes developed for early spring planting was tested for the low temperature stress. Early spring planting inhibited the growth at early stage, but not significantly at later stage. No significant genotype x planting date interaction for growth, yield and yield components, except for leaf area was observed. Genotypes selected for yield, number of productive panicles and panicle weight were relatively stable in different planting date and might be considered as genotypes adapted for early spring planting.

Pearl millet responded differently to photoperiod. The upper part dry weight, 50% heading, grain filling periods, harvest index, grain weight per panicle and grain yield per plant were sensitive characters to photoperiod. The 16 h days increased growth characters as plant dry weight, heading date and grain filling period but decreased yield characters as harvest index, grain weight per panicle and grain yield per plant. Number of productive panicles, panicle length and panicle weight were relatively insensitive characters to photoperiod. As pearl millet can flower under 16 h days but much earlier under 8 h days, it was confirmed as the facultative short-days for the crop.

The procedure of plant regeneration from immature inflorescence was developed for rapid crop propagation of genetically identical materials. Using selected genotypes, high frequency of callus formation and plantlet regeneration was obtained and the chromosome number as 2n=14 was confirmed in root tip cells originated from both germinated seeds and regenerated plantlets.

In conclusion, this thesis revealed many valuable basic informations regarding with
agronomic characteristics of pearl millet. Not only the interrelationships among the characters, but the phenotypic correlations and genetic correlations, genetic gain and the heritability values of the most important characters to grain yield, and the grain yield per se, were obtained. These informations would be very important for developing the successful breeding program of the crop. In addition, the effective selection procedure for improving grain yield was developed. From genotype x environmental interaction study, possibility for developing genotypes adapted to early spring and for late summer grain sowing, which farmers are seldom practicing, will be enhanced. The rapid crop propagation method of genetically identical materials using plant regeneration from immature inflorescence procedure will contribute to widening the breeding method strategy in pearl millet.

ACKNOWLEDGEMENT

Praise to be Allah, Lord of the Universe, Who always protects, guides and supports us in all activities. His compassionates and mercies allows me to complete this work.

The present work was done in the Laboratory of Crop Science, Graduate School Division of Agriculture, Kyushu University, Japan. The completion of this work is also the result of encouragements and supports of numerous person.

My special thanks are due to Dr. Tomohiko Yoshida for his invaluable guidance, advising and stimulating discussion during my work. This work would not have been carried out without his continuous supports and constructive criticism.

I am like wise indebted to Prof. Dr. Matsuo, E. and Prof Dr. Yoshimura, A. for their excellent supervising and guidance especially during preparation of the manuscript which is gratefully acknowledged.

I wish to thank Dr. Tadahiko Furuya, Dr. Toshihiro Mochizuki and Dr.Shao-Hui Zheng for their comments and suggestions. They have been allowed me to use their facilities during the study.

Thanks and appreciations are also extended to Prof. Dr. A. Baihaki for his supports and advises for my study.

I would like to express my thank to all members of Crop Science Laboratory, especially Mr. Nguyen Duy Can, Mr. Won long Gun, Mr. Fukugawa, Mr. Javied and Ms. Sasaki for helping, support and allowing me to use their facilities during the study. They have created a warm and dynamic atmosphere during my study which is greatly appreciated.

Appreciations are extended to the Japanese Government for long term, Monbusho scholarship for my study during three years in Japan.

I want to express my deep gratitude to my parents and extended family for their invaluable help, attention and support during the period of my study. My special thanks to my dear Nita Triana and my sons Hafizh Faikar Ramadhan and Nafarain Agung Haniefan who always inspired me for this personal and great accomplishment.

Their encouragement and understanding during my study have been invaluable.

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