THE EFFECT OF SOME MAJOR GENES ON BIRD DAMAGE EARLINESS AND YIELD OF PEARL MILLET COMPOSITE ICMV 155

M.Sc. Thesis

BY NEGUSSE ABRAHA

Supervisors: Jorgen L. Christiansen
Tom Hash, ICRISAT

The Royal Veterinary and Agricultural University (KVL)
Department of Agricultural Sciences
Plant Breeding and Crop Sciences
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Acknowledgement

I want to express my sincere appreciation to my major supervisor Jorgen L. Christiansen (Associate Professor) and co-major supervisor C. Tom Hash (Principal Scientist) for their guidance, encouragement, assistance and constructive comments throughout my study.

Moreover, I acknowledge with affection and thanks to Brian Dannis head of the department of agricultural sciences at KVL, Olav Stolen (Professor) former head of plant breeding unit at KVL, Sven Bode Andersen (Associate Professor), Rodomiro Ortiz former Nordic Associate Professor of plant genetic resources at KVL, Bjarne Jornsgard (Research Associate), Alice Thomsen (Secretary) and staffs of library at KVL who helped me in organizing and guiding my study and programme during my study at KVL.

Special thanks is extended to the Government of Eritrea, Department of Research and Human Resource Development for providing me a scholarship for M.Sc. studies. Moreover, I acknowledge Danida (Denish International Development Assistance) for financing all aspects of my stay in Denmark and India while studying my masters. I am also very greatful to ICRISAT to allow me to use facilities and assistance of its staff members.

With respectful regards and immense pleasure, I wish to acknowledge and express my thanks to Dr. S. Chandra (Senior Scientist) for valuable advice and unlimited co-operation during designing the plan and analysing the date of the experiment. Further, I wish to express my sincere thanks to Mr. A.G. Bhasker Raj and Mr. Mohammed Ahmeduddin who were assisting and guiding me during my research work.

I am grateful to pass my special thanks to all staffs working in the pearl millet breeding unit, training office and library of ICRISAT for their valuable contribution and assistance during the course of the research.

I am highly indebted to my mother, brother (Tesheme A.), sisters, relatives and friends for their wishes, moral support and encouragement. I also thanks many other people who have directly or indirectly advised me while writing my masters thesis.

Last but not least, I would like to express my sincere appreciation and gratitude to my wife Tazez Tesfay for inspiration, affection, encouragement and looking after my children patiently during the period of my study.

Negusse Abraha

Abstract

Studies were made to ascertain the effects of backcross transfer of the e_l gene for photoperiod-insensitive early flowering on phenology and agronomic performance for grain yield and stover yield in pearl millet. Simultaneously, the effects of backcross transfer of long panicle bristling on grain and stover yield potential and vulnerability of grain to bird damage was also assessed.

Most of the genotypes were affected by extended day length, but ICMV 155 e_le_l was the least affected: this early version of ICMV 155 reached 75% flowering in 49 days under normal day lengths and 51 days under extended day lengths. The homozygous e_l gene conditioned the crop to mature 11 to 14 days earlier than its isogenic counter parts under normal and extended day lengths.

In this experiment, it was observed that the early genotype (e_le_l) bloomed the earliest among the nine genotypes in both normal and extended day lengths. Selection of sowing dates and genotypes had also influenced for days required for this character.

Use of the e_le_l gene can produce pearl millet that is photoperiod insensitive that can grow and mature at the shortest possible duration. Thus in combination with optimal sowing dates and soil fertility rate, the genotype can be useful as a means of drought, pest and disease escape mechanism in areas where a predominantly rain-fed crop is grown and favourable moisture regime is limited. However, this early genotype had low total dry matter production as compared to other genotypes.

When the Bristled genotype was evaluated, it performed well in resisting the bird damage, i.e., the Bristling gene (*Br*) expressed well in protecting from bird damage. It was also comparable with two genotypes which had less damage because the first was a late variety with E_l gene and the second genotype was with the later-flowering genotype with the brown mid-rib gene (*bmr*), which had lodging problems

When this Bristled genotype was evaluated for days to 75% flowering, it was found to be among the genotypes with shorter duration. Therefore, it could be said the Bristling gene (*Br*) had expressed well and the Bristled genotype required a shorter period than the original ICMV 155 (its recurrent parent) for grain production. Moreover, the Bristled genotype was observed to be one of the highest yielding genotypes for total dry matter, in fact it was superseded for this trait only by the late flowering variety with gene E_l.

The Bristled genotype under investigation for its possible resistance to bird damage showed reasonable potential to resist birds even under heavy bird pressure. This resistance was especially effective when birds had a chance of getting other alternative food sources, which was proven during sowing date 2 of this experiment by the higher grain yield of the Bristled genotype.

When the threshing percentage was calculated in the no bird scarer treatment, the highest figure was found by Bristled genotype (16.69%) followed by ICMV 155 E_lE_l(late variety) (15.03%) and *bmr* (14.65%) genotypes. As there was higher panicle threshing percentage, the less the damage of the panicles by the birds.

Declaration

I, Negusse Abraha, hereby declared that the thesis entitled, the effect of some major genes on bird damage, earliness and yield of pearl millet composite ICMV 155 submitted to Royal Veterinary and Agricultural University (KVL) for the master of science in plant breeding and genetics is the result of me. Moreover, I declared that this thesis or any part of this thesis has not been published earlier under any circumstances.

Negusse Abraha

Date: December 1999

Place: Denmark

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1.0. INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is grown mainly for grain in the tropical and sub-tropical areas of Africa and the Indian sub-continent. It is an indispensable food for millions inhabiting the semi-arid and arid tropics and is more important in the diet of the poor (Harinarayana, 1987). Pearl millet grain is among the most nutritious of the major cereals. Its protein content is not only high, but of exceptionally good quality, being seriously deficient only in lysine. It also has good levels of phosphorus (52% phytin) and iron, and reasonable quantities of thiamine, riboflavin, and nicotinic acid (Rachie and Majmudar, 1980). Its traditional role in the life of people in all growing areas is reflected in its use in traditional dishes, and its inclusion in religious rites, traditions, and kinship patterns (Khairwal et al., 1990). The major types of foods produced from pearl millet grain are (a) porridges, either thick or thin, which are common in west Africa and (b) flat bread, either unfermented (mostly Asia) or fermented (Eritrea and Sudan)

Africa is one of the two major pearl millet growing regions in the world. In Africa, 70% of the pearl millet produced is grown in western Africa (Kumar, 1989). The major pearl millet producing countries are India, Pakistan and Yemen in Asia; Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania and Senegal in western Africa; Sudan and Uganda in eastern Africa and Namibia in southern African. Pearl millet is also grown in Eritrea on a total area of 47,000 hectares, and is third in importance among cereals following sorghum and barley (MoA Annual Report, 1997). It is widely used as grain crop in the western and eastern lowlands of the country whereas its use as forage is limited. The bulk of the crop is grown in areas where annual rainfall is 200-800 mm/annum and is received between the months of May and October. Farmers in Africa usually intercrop pearl millet with other cereals like sorghum and maize, or legumes like cowpea and groundnut. The most widely used of intercropping system is pearl millet-cowpea in the south Sahelian zone of west Africa (Fussell et al., 1987).

Pearl millet is the fourth most important food crop in India, after rice, wheat and sorghum (Harinarayana, 1987). It is important in the states of Rajasthan, Maharashtra, Gujarat and Haryana but it is also grown in other parts of India where the rainfall is 150-750 mm/annum, primarily during the south-west monsoon from June to September (Kumar, 1989). Farming in these areas is often traditional with considerable use of local varieties (especially in Rajasthan), which are late, tall and have poor grain yield potential resulting in low total production.

Under the situation of subsistence farming that exists in pearl millet production areas of both India and Africa, grain yields are limited by the poor inherent fertility and water holding capacity of the soil and traditional management practices, including limited use of fertilizers and below optimal levels of tillage. Further limitations are imposed by droughts, sand storms, high soil temperatures at the beginning of the season, insect pests, diseases, the root parasite *Striga* and the low genetic yield potential of traditional landraces (Kumar, 1989).

There is a common belief that pearl millet is drought-resistant or more efficient under limited moisture and stress conditions. Rachie and Majmudar (1980) explained that comparative experiments with sorghum and pearl millet do not support the opinion that pearl millet is necessarily more drought-resistant per se than sorghum. Rather, millet derives its advantage from having of a shorter crop life cycle and having greater heat tolerance. Other factors that contribute to the superior performance of pearl millet on dry lands are its excellent adaptation to light sandy soils, its tolerance of low soil fertility, and its tolerance to soil acidity and/or salinity. These characters vary according to genotype, and some desert strains with non-synchronous tillering habit, such as the *Chadi* landrace of Rajasthan, may be better able to cope with a low, sporadic rainfall pattern than the more robust-growing, uniform-tillering strains of higher-rainfall regions.

Pearl millet can also be grown as forage crop. The crop is a productive warm season annual, readily established using conventional equipment and has much lower water requirements than maize grown for silage (Pedersen, 1997). On the other hand, the usefulness of pearl millet forage incorporated into diet of ruminants is limited by the quality (and quantity) of lignin it contains. Digestibility of the forage is affected by the amount and quality of lignin in the cellwalls, since the most important constraint to digestion of plant cellwalls is lignin (Cherney et al., 1991). Other characteristics, including plant colour, sweetness, juiciness and even seed pericarp colour can affect forage quality (Pedersen, 1997). Although most forage quality parameters appear to be quantitatively inherited, several simply inherited qualitative characters like brown midrib can have significant impacts in forage nutritional quality (Andrews and Kumar, 1992).

Several efforts have been made to improve pearl millet grain yields using different breeding methods. Pearl millet breeding began in both India and western Africa in the early 1930s and in eastern Africa in the early 1950s with emphasis on grain production (Kumar, 1989). On the Indian sub-continent, attempts at variety improvement included introduction of exotic materials, inbreeding, some recombination of characters by crossing and selection or purification of open-pollinated varieties (Rachie and Majmudar, 1980). There was also research done on the pearl millet population development in the Sahelian and Sudanian Zones of western Africa, primarily involving selection for grain yield, downy mildew resistance and resistance to insect pests (Rattunde et al., 1997).

Andrews and Kumar (1992) have mentioned pearl millet research to develop combine phenotypes using major dwarfing genes, maturity control through both photoperiod-insensitivity and independent maturity genes, and improving levels of tolerance to heat and moisture stress. There are also several systems of cytoplasmic-genic male sterility available to exploit well-manifested hybrid vigor in this species. Although pearl millet has great agricultural importance, and is a very favourable organism for cytogenetic studies and breeding work, the information available on its genetics and cytogenetics is far less than that for other important crops (Kumar and Andrews, 1993). It has long been considered to be a crop of secondary importance and restricted area of use, and been a food only for the poor (Khairwal et al., 1990)

Current pearl millet breeding efforts in India and North America are aimed at exploitation of hybrid vigor. Elsewhere in Asia, Africa and South America, improved open-pollinated varieties are the breeding products reaching farmers. Although maximization of grain yield (or forage yield in the case of forage varieties) is an overriding consideration, up-grading grain and stover nutritional quality also remains an important goal of plant breeding (Jauhar, 1981). Further, dwarf hybrids with improved disease resistance and better grain quality are being evolved. Plant breeding is, of course, an ever-continuing effort aimed at tailoring plants to meet human needs. Modern cultivars, be they hybrids or open-pollinated varieties, must be genetically broad-based, to confer some sort of built-in insurance against future disease problems.

OBJECTIVES

The present investigation was under-taken in a common adapted genetic background with a view to

1. Determine the effects of backcross transfer of the e_1 gene for photoperiod-insensitive early flowering on phenology and agronomic performance for grain and stover yield.
2. Determine the effects of backcross transfer of long panicle bristling on grain and stover yield potential, and vulnerability of grain to bird damage.
3. Determine the effects of date of sowing and top-dressing rates on grain yield and quality of the crop.

2.0. LITERATURE REVIEW

2.1. THE EFFECT OF MAJOR GENES ON FLOWERING TIME

Agriculturally, it has long been appreciated that the time from sowing until flowers first appear is a principal determinant of relative maturity and adaptation to the cropping environment (Whyte, 1964).

Early flowering is important for pearl millet as it provides an opportunity for escape from terminal drought stress in normal sowing dates in northwestern India or in later sowing dates in the sorghum-millet transition zones of peninsular India. Relative insensitivity to photoperiod is also likely to contribute to wider adaptation across pearl millet production areas in peninsular and northern India (Talukdar et al., 1993). Further, Bidinger and Rai (1989) explained that although early flowering photoperiod-sensitive genotypes are suitable in northern India, they perform poorly in the peninsular zone of that country as the shorter day lengths there result in very short vegetative periods. Since pearl millet is a short-day plant (Begg and Burton, 1971), its flowering will be earlier in shorter than in longer day lengths; and hence will be shorter in lower than in higher latitudes.

A low degree of photoperiod sensitivity is a requirement for broad adaptation in a short-day species such as pearl millet. There is a considerable variation in the growing-season length across the major pearl millet growing areas both in the Indian subcontinent and western Africa (Bidinger and Rai, 1989). In both cases, shorter growing seasons (8-12 weeks) are at higher latitudes, although the actual latitude of millet cultivation differ considerably between northwestern India (21-28° N) and the western African Sahel (13-15° N).

2.1.1. DESCRIPTION OF PHOTOPERIOD

Photoperiod response is one of the many environmental adaptation factors that are of critical importance in the utilisation of pearl millet germplasm and in the characterization of many traits (Andrews and Kumar, 1992). Whereas, a few important traits, such as grain color, are relatively independent of environmental effects, many others, such as grain and forage yield and quality are strongly affected.

Photoperiodism, the growth response of plants to definite light and dark periods, was first described by Garner and Alland in 1920. Since then, this fascinating phenomenon has been observed in many flowering plants (Burton, 1965). There are three main categories of response to day length. These are photoperiod-insensitive or day-neutral plants (DNP), short-day plants (SDP) and long-day plants (LDP). Within the two photoperiod-sensitive categories there are species and genotypes with obligate (absolute or qualitative) responses and others with quantitative (or facultative) responses (Vince-Prue, 1975).

The requirement for a short-day plant for flowering is that the day length has to be shorter than the ceiling photoperiod, which is a particular value for a particular genotype. In contrast to these obligate responses, a quantitative response is one in which flowering is delayed but never prevented in less inductive photoperiods, i.e., in longer days for short-day plants and shorter days for long-day plants.

Since time of maturation is an important factor in the adaptation of tropical cereals, particularly in respect to yield and quality, flowering in almost all pearl millet landraces varieties is retarded by long days and induced by short days (Burton, 1965). This photoperiod sensitivity, which differs minutely between cultivars, permits flowering and hence, grain maturation to coincide with the time when the rainy season usually ends each year, largely irrespective of the date of sowing. This relatively uniform maturation despite sowing date variation, ensures good seed and grain quality and minimizes losses to terminal drought stress and grain-feeding birds.

2.1.2. INFLUENCE OF PHOTOPERIOD ON FLOWERING

Many, perhaps most, genotypes of the world's major annual crops are photoperiod-sensitive with respect to the onset of flowering. During their basic vegetative growth phase, i.e., the pre-inductive phase, most annual plants are insensitive to photoperiod, whereas during their inductive phase, they are sensitive to (and the length of this phase is therefore dependent on) photoperiod (Roberts and Summerfield, 1987).

Days to flowering alone can not differentiate phototoperiod sensitivities. The most visually obvious trait that unambiguously differentiates the photoperiod-insensitive genotype from the photoperiod-sensitive one is the occurrence versus non-occurrence of a flush of flowers at the apex of the determinate main stem (Wallace et al., 1993a) under non-inductive day lengths. In case of obligate photoperiod sensitivity, such a flush of flowers does not occur for any plant of the homozygous-sensitive genotype. In four independent studies, Wallace et al. (1993a) showed the delay in flowering of photoperiod-sensitive bean (*Phaseolus vulgaris*) resulted because long day length caused flower buds to grow slower and/or to abort.

Wallace et al. (1993b) had a similar experiment to see the effect of photoperiod gene(s) and daylength on crop yield and its three major physiological components (aerial biomass, harvest-index and days to harvest maturity) on beans and groundnut. They reported photoperiod-sensitivity gene(s) delay time to flowering and/or time to maturity in non-promotive day lengths while simultaneously lowering the harvest-index.

Lawn and Williams (1987) reported that in many species, flowering becomes irreversibly induced by the end of inductive phase so there is typically a final photoperiod-insensitive phase that precedes the appearance of the first flower. In some species, however, the flowering stimulus can be reversed, even when floral buds are relatively well-developed, so that this post-inductive phase may be very short or even absent. Then again, although the photoperiod experienced during the post-inductive phase may not affect the time of appearance of the first flower, genotypes of some species (e.g., soyabean and wild *Vigna* spp) can be returned to the vegetative condition by non-inductive cycles applied during this phase because the initiation of the development of subsequent flowers is affected.

The term critical photoperiod has been defined in various ways. According to Summerfield et al. (1991), for short-day plants such as pearl millet, the critical photoperiod is that day length which, if exceeded, causes a delay in flowering. With further increase in day length there comes a point, the ceiling photoperiod, when the time taken to flower reaches a maximum number of days. If this maximum value is finite then response is quantitative; i.e., long days delay flowering but, even if they are longer than the ceiling photoperiod, they do not prevent it. If, however, there is an infinite delay at the ceiling photoperiod and in longer day lengths (i.e., if the plants never flower), then the response is obligate. On the other hand, in long-day plants the critical photoperiod is that day length below which there is a delay in flowering and the ceiling photoperiod is the longest photoperiod in which maximal delay is achieved. Again, if this delay is infinite the response is obligate whereas if it is finite the response is quantitative.

2.1.3. THE RELATIONSHIP OF PHOTOPERIOD AND TEMPERATURE

Early flowering under field conditions does not necessarily indicate photoperiod insensitivity. It can equally well result from the hastening effect of high temperature, optimal soil moisture and fertility conditions an appropriate inductive photoperiod, or an inherently short vegetative growth period. Photoperiod insensitivity must be assessed by comparison of time to flowering in different day lengths. Wallace et al. (1993b) have also demonstrated that day length and temperature are the primary environmental controls over time to flowering and maturity, cultivar adaptation and yield.

Summerfield et al. (1991) have described the effect of temperature on the time of flowering. Temperature can affect time from sowing to flowering in three ways:

1. There may be a specific cold-temperature induced hastening of flowering known as vernalization.
2. Over a wide range of temperatures the rate of progress towards flowering increases with increase in temperature to an optimum temperature at which flowering occurs in the minimum possible time given other environmental conditions.
3. At supra-optimal temperatures flowering is progressively delayed as temperatures get warmer.

Further, when photoperiod-insensitive genotypes and photoperiod-sensitive genotypes are maintained in a given constant photoperiod, the rate of progress towards flowering is a positive linear function of temperature from a base temperature at which the rate is zero, up to an optimum temperature at which it is maximum. There is considerable evidence that in both short- and long-day plants at any mean daily temperature between base and optimum temperature, the relationship between photoperiod and the rate of progress towards flowering is linear between the critical and ceiling photoperiods. Outside this temperature range, variation in photoperiod has little or no effect on the time plants take to flower.

The relationship of temperature and photoperiod with pearl millet flowering time was also discussed by Ong and Monteith (1985). Temperature exerts a major effect on the rate at which crop plants develop and on processes of expansion and extension. Light availability determines the rate of growth (i.e., dry matter production) at any stage of the development. But there are important interactions: development can be slowed by low light intensity or short light duration, and growth can be retarded when the temperature is too high or too low. Further, temperature is the main factor determining the time from sowing to maturity for an annual crop and the availability of light within the growing season sets an upper limit to the amount of dry matter that the crop can accumulate when water and soil nutrients are abundant.

In addition Ong and Monteith (1985) studied vegetative and reproductive plants and suggested that although differences are small they may exist when the dominance of the main stem is modified by photoperiod or when the light regime within the canopy is modified by the temperature or plant spacing. In long days, for example, the longer duration of growth stage one increased the number of tillers produced mainly because tillering continues for a longer period (Ong, 1983). When light competition is reduced or delayed by decreasing plant population or reducing temperature, tillering increases dramatically. In an experiment carried out in Niger on pearl millet (Indian single-cross hybrid BK 560), Azam-Ali et al. (1984) observed a stand with 2.9 plant m^{-2} had 2.8 times more tillers per plot than a stand with 11.5 plant m^{-2}.

Temperature has a major influence on the final number of tillers produced, the productivity of basal tillers and tiller survival. Although tillers can make up over 60% of the total dry matter of the crop, they can contribute as little as 0 to 15% of the grain yield when many fail to produce grains. Egharevba (1977) concluded that, in Nigeria, reducing tillers from ten to three or five consistently increased grain yield of pearl millet (Ex-Bornu) by 15 to 30%. On the other hand, uniculm plants yielded about 20% less than the high tillering control.

2.1.4. IMPORTANCE OF SHORT DURATION

In areas where a predominantly rain-fed crop is grown and hence the favourable moisture regime is limited, a short-duration, catch crop would be more successful. For such varieties, genes for photoperiod insensitivity may need to be incorporated to bring about early maturity. The availability of such short-duration varieties will also permit the farmers to take more than one crop in a year (Jauhar, 1981). Uniform early maturity in such varieties will improve adaptation to short rainy seasons and double cropping schemes as well as reduce the period that the crop is exposed to potentially damaging biological and physical stress (Thakur and Williams, 1980). Uniform pollen fertility restoration also may help to insure good seed set and reduce the incidence of infection by grain replacing fungal diseases.

El Hag Hassan Abuelgasim (1995) repeated an experiment on performance of elite pearl millet varieties under dry conditions in Sudan and observed the grain yields obtained, ranging from 146 to 392 kg ha^{-1}, were generally low mainly due to the low total and poor distribution of rainfall. However, early-maturing varieties (90 days or less) gave better grain yields than the late-maturing ones.

When conditions of temperate zone agriculture are considered, photoperiod-sensitivity often constitutes a formidable barrier to use of genetic diversity found in short-day sensitive germplasm of many field crops. Breeders of field crops such as maize, sorghum and pearl millet are often unable to make the field pollinations between plants that differ widely in their response to photoperiodism (Barnes and Burton, 1966). Further, genotypes of these tropical cereals that require less than a 12-hour day to initiate floral primordia frequently fail to reach anthesis or mature seed in temperate environments. If research workers are to continue to improve varieties and hybrids, new source of germplasm will be useful. Therefore, methods should be developed so that short-day germplasm can be made available in a more useful form to research workers in both tropical and temperate areas.

Early maturity and photoperiod insensitivity are highly desirable characteristics in grain crops, often extending their area of adaptation, permitting more than one crop per season and enabling them to mature grain in arid regions where later-maturing cultivars could fail (Burton, 1981). Several important traits in pearl millet are controlled largely by major genes (Kumar and Andrews, 1993). These include a recessive gene (e_1) for photoperiod-insensitive early maturity.

2.1.5. THE APPLICATION OF e_1 GENE IN PEARL MILLET PRODUCTION

Mutations for early maturity can help cultivars escape adverse environmental conditions and fit into double cropping systems. Hanna and Burton (1985) had an experiment to see the effect of morphological characteristics and genetics of two mutations for early maturity in "Tift 23" pearl millet. They reported plants with the e_1e_1 genotype or the e_2e_2 genotype flowered in 49 and 38 days, respectively, after sowing on 12 June compared 76 days for Tift 23, the normal E_1E_1, E_2E_2 counterpart. Furthermore, both mutants with e_1 and e_2 genes had significantly ($P < 0.01$) shorter plant height, shorter panicles and thinner stems than their normal counterpart. They concluded the e_1 gene has immediate potential use for producing early maturing inbreeds and hybrids. The e_2 gene conditions plants to mature up to 10 days earlier than the e_1 gene but will require backcrossing and selection to eliminate some undesirable characteristics. Both genes should be useful in improving the grain yield potential of pearl millet.

In pearl millet, the e_1 gene conditions plants to mature 10 to 40 days earlier than the isogenic normal line and to be photoperiod insensitive. It was discovered as a naturally occurring mutation in the Australian forage cultivar 'Katherine' (Burton, 1981). A sowing date experiment confirmed earlier observations that lines homozygous for e_1e_1, such as Tift 23DBE, reach anthesis in 45 to 55 days regardless of the sowing date whereas their normal E_1E_1 counterparts flowered in 75 to 85 days if sown in May and 55 to 65 days if sown in August. Moreover, the e_1 gene imparts earliness and makes most pearl millet genotypes homozygous for it mature 10 to 40 days earlier than their normal E_1E_1 counterparts. Thus it appears that the e_1 gene, when homozygous, removes photoperiod sensitivity in pearl millet and imparts unusually early maturity.

The allele of the e_1 gene studied by Burton (1981) and in experiments described in this thesis was isolated in 1968 by repeated backcrossing from a weak, spindly, very early maturing seedling discovered by R. F. Moore in a field of 'Katherine' pearl millet growing in Queensland, Australia. The e_1 gene, and a rapid backcrossing program, make it possible to quickly create very early, photoperiod-insensitive forms of any superior pearl millet cultivar or hybrid. Such cultivars and hybrids should possess the adaptation, pest resistance, quality and short day length agronomic performance of their normal counterparts under both short and long day length conditions. Their earliness and photoperiod insensitivity can extend their usefulness and make pearl millet a more valuable crop to man.

2.1.6. EFFECTS OF PHOTOPERIOD ON FLOWERING TIME IN PEARL MILLET

Extending the day length can influence the time of panicle initiation and flowering. Extended photoperiod imposed on short-day pearl millet grown in controlled environments, lengthened the time taken to anthesis and increased plant height, number of leaves and dry weight (Begg and Burton, 1971). A similar experiment was conducted by Ong and Everard (1979). They observed reduced panicle numbers per plant under extended photoperiods, which generally contributed to reduced biomass yield. A reduction in the number of productive tillers per unit area in both tall and dwarf hybrids was also described under extended photoperiods at Hyderabad, India (ICRISAT, 1985); however, grain yield increased in the tall hybrids but decreased in the dwarf hybrids under the extended day length regimes.

Carberry and Campbell (1985) found that the extent of delay to the initiation of the panicle was dependent on the number of additional hours of supplementary light per day. Longer photoperiods applied during vegetative growth had no effect on the duration of panicle development but resulted in a slight decline in the duration of grain filling. as photoperiod increased from 13.5 h to 15.5 h, time taken to panicle initiation increased from 16 to 34 days in a pearl millet hybrid. Further, Barnes and Burton (1966) found that pearl millet male-sterile line Tift 23A flowered much earlier (under short day lengths) in Puerto Rico than under long day lengths and artificially extended (13.5 and 14.5 h) day lengths in the USA.

Similarly, Talukdar et al. (1993) had an experiment on 7 pollinators with good specific combining ability for yield under normal (11.6 and 12.5 h) day lengths in Patancheru and naturally occurring long day lengths (14.5 h) in Hisar. They reported that correlations between time to 50% flowering at Hisar and in each of the four trials grown at Patancheru were lower for the F_1 hybrids alone than the combined F_1 hybrids plus parents. Moreover, the strongest positive associations of phenology were between Hisar and the Patancheru summer extended daylength nursery for both the hybrids and the progenies plus parental lines. One possible reason for this is the interaction of light and temperature in determining growth and development processes (Ong and Monteith, 1985).

Carberry and Campbell (1985) examined pearl millet hybrid BJ 104 at ICRISAT, Hydrabad, India over a range of population densities (50,000 to 400,000 plants/ha) and during early vegetative growth imposed three photoperiods. At a given plant population density, lengthened vegetative growth duration at longer photoperiods resulted in greater plant dry weights at panicle initiation. Both leaf and stem dry weighs increased, while the leaf fraction remained constant. As the photoperiod lengthened from 13.5 to 14.5 and 15.5 h, they observed the period for panicle initiation of the main axes increased from 16 to 25 and 34 days after emergence, respectively. Final plant height also increased from 1.56 ± 0.02 m to 2.23 ± 0.04 m and 2.43 ± 0.04 m, respectively. In addition, the grain yield per plant showed no significant difference between photoperiods at high populations (at which tillering was limited), but as population declined the yield per plant of the normal photoperiod increased dramatically over that of both extended photoperiods.

The duration of the vegetative phase (DVP) in pearl millet, which is the major cause of variation in crop duration, has marked effects on the number of productive tillers per plant and on the main shoot and tiller grain yield (Craufurd and Bidinger, 1988). They too observed no effect of DVP treatments (induced by varying photoperiod) on grain yield per plant. Although the yield of the main stem was increased in the longer DVP treatment, this was associated with reduced yield from subsequent tillers due to reduced numbers of grain bearing panicles per plant. Grain yield on each shoot was directly proportional to shoot growth rate. The major limitation to increased yield potential in longer duration pearl millet is the reduction in harvest index resulting from relatively greater effect of long DVP on the stem growth, both rate and duration, compared to panicle growth. Selecting for increased numbers of panicles is unlikely to result in a significant increase in yield potential because of the inverse relationship of panicle number with panicle size. A similar trial was conducted by Craufurd and Bidinger (1988) to see the effect of crop duration on plant phenotype in two hybrids using extended day lengths that increase the duration of the vegetative phase (GS1= sowing to panicle initiation). They reported the duration of GS1 was increased from 20 to 30 days, resulting in increased numbers of leaves, leaf area and stem and total dry-matter accumulation. However, there was no effect on tiller production and survival, or panicle growth rate. Grain yield was, therefore, the same in both GS1 treatments, and harvest index (HI) was much reduced in the long GS1 treatment owing to increased stem growth. Thus, the major limitation to yield improvement in crops with a longer duration of GS1 is the failure to translate the extra dry matter accumulated into increased panicle and grain growth. These results are in line with an earlier study where longer vegetative phase did not result in longer tillering phase because tillering ceased when the canopy closed and stem growth started (Ong, 1984)

In pearl millet, grain yield and grain number per panicle can be influenced by extending the vegetative development phase. Alagarswamy and Bidinger (1985) reported that being quantitative short-day plants, all the varieties under trial reached panicle initiation, flower and maturity earlier in normal day lengths than in extended day lengths. Delayed panicle initiation markedly increased leaf numbers and plant height. Moreover, the delay in panicle initiation caused by extended day length reduced panicle numbers per plant at maturity, and increased grain numbers per panicle. They concluded that it was possible to increase grain numbers per panicle and total crop dry matter by increasing the length of the vegetative period. However, this was not reflected in increased grain yield because the increase in grain numbers per panicle was offset by decreases in panicle number. Thus, small increases in the duration of GS1 result in significant increases in pearl millet leaf area and total dry weight at flowering. However, this increase in dry matter neither supported more productive tillers nor resulted in an increase in grain yield. It appears that there is a negative relationship between the duration of GS1 and number of productive tillers when a given genotype is grown under a range of photoperiods.

2.2. EFFECT OF MAJOR GENES ON VULNERABILITY TO BIRD DAMAGE

2.2.1. GENERAL DESCRIPTION OF BIRDS AND BIRD DAMAGE TO CROPS

It has long been known that apart from losses caused by pests and diseases, an appreciable loss to standing crops also results from attacks by birds. Birds are a constant menace to pearl millet grain or seed production in most regions (perhaps even more so for this crop than for sorghum), unless the crop is grown to coincide maturation with other bird-attractive crops, including large tracts of millet and sorghum (Rachie and Majmudar, 1980).

Similarly, Ali (1996) indicates that although birds can be used by man as destroyer of insect pests and other vermin (rats and mice – which do enormous damage to crops and agriculture produce), as scavengers, flower-pollination agents, seed dispersers, and as food, some are also injurious to man's interest in a number of ways. They destroy his crops, and damage his orchards and vegetable gardens.

Saini et al. (1994) reported on the food of the rose-ringed parakeet (*Psittacula krameri*), which was very common in the current experimental area. They reported 45% of the total food of this bird was cereals followed by tree seeds (38%). Moreover, pearl millet, sorghum and maize were consumed as significant proportions of this bird diet during August and September. The relative proportion of pearl millet exceeded that of any other cereal in both August (22%) and September (40%). This bird has been rated as the number one pest of agriculture and horticulture in India (Ali and Ripley, 1983).

2.2.2. BIRDS IN AFRICA

Birds are believed to be the most serious pests of pearl millet in Africa. According to Mallamaire (1959), the most important bird pests on this continent are *Q. quelea quelea*, *Q. quelea aethiopica* and *Q. quelea centralis*. *Q. quelea aethiopica*, which is a mountain race, is prevalent in eastern Africa, from Eritrea, Sudan and Ethiopia south to Uganda, Kenya and Tanzania. In Eritrea, vulnerability to bird damage may be one of the major causes for reductions in land allotted for pearl millet over time (Amanuel, pers. comm.).

The greatest difficulty in plant protection of pearl millet occurs during the maturation and ripening of grains, when birds of several species attack the crop. Crops most affected are those that commence maturing before or after the main season, or that are physically located near roosting and nesting sites. Farmers in the drier part of Africa face substantial losses of their ripening cereals to bird pests, particularly the *Quelea* sp. Since time immemorial, flocks of these birds have sporadically raided fields of sorghum and millet (Ward, 1973). Elliot (1981) has described the losses of crops to birds in eastern Africa and estimated an annual minimum of US$15 million, with the *Quelea* being the major deprecator. Moreover, damage is sporadic and varies from place to place within the same region or country.

The bird pest problems in Uganda appear to be more complicated than in the rest of eastern African countries and vary from season to season and place to place (Ash, 1983). The main factor hindering a quantitative estimate of damage due to birds is the traditional methods of agricultural practiced in much of the country (which is partially true of the other countries). However, estimates of grain losses can be readily obtained in marginal farming areas like Karamoja or on large mono-crop areas such as the Kibimba Rice Scheme. In 1983, the yield losses of rice in Kibimba due to bird pests was estimated to be 15% for one season (Okurut Akol and Molo, 1985).

In western Africa, the main bird pest is the weaver bird, Q. *quelea quelea*. It is extremely gregarious, nests in trees and brush in the savannah areas and frequents the region between 12 and 17°N, between St. Louis in Senegal and Lake Fitri in Chad. The major nesting areas, totalling 14,000-17,000 ha, are the Senegal Valley, the central Niger River delta in Mali and the Yelimaine area (Lake Chad and eastern Niger to Chad and Cameroon). The total *Quelea* population in these three areas, estimated at 1.5 billion, waste or consume an estimated of 1 million tons of grain annually (Rachie and Majmudar, 1980). Further, birds also substantially restrict or prohibit use of certain promising crop and fodder species and cultivars in these regions.

The problem that the *Quelea* spp. pose to agriculture comes from the birds' enormous numbers. Even though 95% or more of theirs dietary intake comes from the seeds of wild grasses such as *Echinochloa, Panicum, Oryza* and *Sorghum* including *Sorghum purpureosericeum*, these birds also attack cultivated sorghum (*Sorghum bicolor*. Moench) and pearl millet (Elliot, 1985). One of the highest levels of bird damage ever reported was 51% in 35,000 ha of sorghum on the Jijiga plain of Ethiopia. This amounted to 18,000 tonnes of grain destroyed by the birds. In Sudan, damage levels in sorghum of 25% (caused by *Quelea* and doves) were reported over 5,200 ha at Rahad River, Kassela province, and actual measurements on 15 ha at Basunda estimated 35-40% crop loss.

2.2.3. BIRDS IN THE INDIAN SUB-CONTINENT

Birds are a very serious problem on pearl millet in India. Some 2,100 species and subspecies of birds comprise the avifauna of the Indian subcontinent and Ceylon (Ali and Ripley, 1987). Moreover, about 350 forms are extra-limital seasonal immigrants, meaning that they breed outside India, mostly in the Palaearctic regions beyond the Himalayas in central and northern Asia, and eastern and northern Europe. Rachie and Majmudar (1980) listed the most important bird pests of pearl millet in the Indian sub-continent are house sparrows (*Passer domesticus* Linn.), parakeets (*Psittacula* sp.), yellow-throated sparrows (*Gymnorrhis xanthocallis* Burton) and crows (*Corvus* sp.).

2.2.4. BIRDS AND CROP DAMAGE

In India, sparrows are considered the major pest problem for ripening fields of pearl millet, sorghum, sunflower, and paddy. They can seriously damage small experimental plots such as pearl millet nurseries (Sarwar and Murty, 1982). In kharif (monsoon rainy period) 1980, Sarwar and Murty observed that the pearl millet experimental downy mildew sick plot nursery (about one acre) at the college farm of Andhra Pradesh Agricultural University was damaged to an extent of 100%.

Birds' damage is very conspicuous. Flocks of birds entering the field are easily seen by farmers and often cause great anxiety. Even if all other aspects of farming, such as land preparation, use of fertilizers, weed control and rainfall may have a much greater influence on production than losses due to birds, farmers often identify birds as their number one enemy. However, a large proportion of the normal food of birds consists of insects, including many that are in the highest degree injurious to man and his concerns (Ali, 1996).

There are two ways in which birds cause damage to cereal crops, by what they actually eat and by what they destroy or waste while eating. The most famous of the bird pests, the red-billed quelea (*Quelea quelea*), eats between 2 to 5 gm of grain per bird per day (Elliot, 1987). The amount of additional damage depends on the stage of development of the crop. At the milky stage, many grain eating birds simply pinch the grain and suck out parts of the contents. The amount the bird gets is small, but it attacks many grains. When the crop is in the dough stage or finally ripening, birds often pull off the individual grain, manipulate it in their beaks to remove the husk and drop pieces of the grain on the ground. One of the signs of serious damage by birds in cereal crops is a scattering of bits of grain and husks on the ground between the plants. In addition, large flocks of birds rising and falling onto the crop often cause a lot of grain to be knocked to the ground.

Bird damage starts at the time of sowing. The birds that which uproot freshly sown seeds include francolins and guinea fowl although small graminivores such as sparrows and *Quelea* also sometimes dig out seeds. The extent of damage often depends on the depth to which the seed is sown, particularly if this is done by machine. A small increase of even one centimeter may put the seed out of the reach of the birds' beaks. Once the seeds have germinated, birds seldom take any interest in the crop until milky stage is reached. However, the purple moorhen (*Porphyrio porphyrio* Linn.) will graze pearl millet seedlings, severely damaging small plots sown near irrigation tanks at ICRISAT, Patancheru (C. T. Hash and A.G. Bhasker Raj, pers. comm.).

Parasharya et al. (1995) observed birds feeding on ripening sorghum grown under isolated conditions. They observed the feeding pattern was bimodal with morning and evening peaks. The density of birds, species richness, their diversity and evenness were greater during the morning peaks than those of the evening. Bird density and species richness were extremely low during the midday hours. Further, the extent of damage varied from 39% to 74% in different parts of the field. This high degree of damage was mainly attributed to the isolated location of the site and leaving the field unprotected.

Jain and Prakash (1974) made a survey of bird damage on pearl millet at the Central Research Farm of the Centeral Arid Zone Research Institute, Jodhpur, Rajasthan, India. They estimated crop loss due to birds from maturity until harvest of the crop. Some 8-10% of grain of the standing pearl millet crop was lost. Further, they made an observation on two varieties (R.S.K. and hybrid pearl millet) and reported that the estimated loss of grain due to bird has been 80 ± 22 kg ha^{-1} for R.S.K. and 144 ± 22 kg ha^{-1} for the hybrid.

The roseringed parakeet has been reported to be very destructive to crops and ripening fruits thus reducing subsequent yields. The bird eats by gnawing, thus wasting far more than what it actually consumes (Ali and Futehally, 1967). Ali (1977) has also mentioned that the bird has a wide distribution over almost the whole of India, Pakistan, Bangladesh, Nepal, central Burma and Sri Lanka. Ramzan and Toor (1973) conducted an experiment on maize crop losses due to roseringed parakeets and reported an average of 12.4%, which varied from 10.1 to 16.5%, was damaged or wasted. A survey on fruit growing areas of Pakistan made by Shafi et al. (1986) reported an average damage of 8.6%, which varied from 2.6 to 12.7%.

In addition to direct damage caused by birds (e.g., *Quelea*), they may cause subtle indirect constraints on sorghum and millet production. In Eritrea, vulnerability to bird damage may be one of the major causes for reductions in land allotted for pearl millet over time (Amanuel, pers. comm.). In many parts of Africa, farmers living in the semi-arid areas are being encouraged to return to cultivating sorghum and pearl millet in preference to maize. For instance, in central Tanzania sorghum will give a reasonable yield in almost every year whereas maize will fail six out of every eight years (Elliot, 1985). However, the greater vulnerability of sorghum and pearl millet to damage by birds is a constraint to more widespread adaptation of these more drought-tolerant alternatives to maize.

2.2.5. TECHNIQUES OF CONTROLING BIRD DAMAGE

Even though control of bird damage is laborious and costly, Okurut Akol and Molo (1985) have suggested some techniques for reducing bird damage.

1. Bird resistance breeding in cereals.

   In breeding for bird resistance in cereals, the potentially useful characters include long and large glumes, long and stiff awns, pendant panicles, and non-palatable, large-sized grains. Other characters include dense panicles, short straw with uniform height and maturity.

2. Agronomic practices

   The agronomic techniques that should be examined in order to try to reduce bird damage include crop replacement, mixture of several crop species, crop management and having large areas that mature at the time.

3. Traditional methods

   Traditional methods of control include trapping, use of disturbing auditory devices, and throwing missiles.

4. Use of repellents

   Repellents are chemicals (e.g., methiocarb) that can be applied directly to the crops to repel the birds that damage them. The birds are discouraged from feeding on the treated crop and sometimes make distress calls to warn-off others.

5. Lethal control

   This technique involves the use of avicides like fenthion. They are sprayed in the roosts or colonies of bird pests using ground sprayers or aircraft.

The Indian baya weaver (*Ploceus philippinus* Linn.) is a common crop pest causing considerable damage to cereal crops. These birds commence visiting the field in flocks from the time crops are in milky stage of grain filling and continue to cause damage until the crop is harvested (Hamid Ali et al., 1980). One means of controlling birds can be the use of distress calls. Swamy et al. (1980) conducted three trials on control of bayas using bioacoustic methods (distress calls). They observed the birds dispersed when they heard the distress calls. Further, they concluded such a technique is effective in moving bayas from their roosts.

Most of the agronomic techniques that can be used to reduce bird damage have been developed and are practised by farmers. Keeping fields free of weeds will keep off birds that might be attracted by wild grass seeds (e.g., love-grasses *Eragrostis* spp and foxtails *Setaria* spp). In addition, adjustments to the crop calendar allows crops to mature when birds are away or their attention diverted to wild grass seeds available in the area. However, it is difficult to implement this since variable factors such as weather at the time of sowing are major controlling agents (Okurut Akol and Molo, 1985). In order to successfully carry out any of these agronomic techniques, the bird ecology, behaviour and feeding habits need to be known fully.

To protect ripening grain production plots, the simplest technique is to do what has been done in Africa and Asia for thousand of years, namely scare the birds out of the fields before they have time to do damage. Studies have shown that an able-bodied, energetic and motivated person can protect at least one hectare of crop, but finding such people is not necessarily easy (Elliot, 1987). Often the amount paid to bird scarers is not enough to motivate them. Moreover, to be effective bird scaring has to begin at first light and continue to dusk. This makes for long days of continuous vigilance. Even though there is shortage of labour, the method is relatively inexpensive for the subsistence-level farmers so bird scarers continue to be used (Okurut Akal and Molo, 1985).

Among earlier technological controls attempted were burning of nests and vegetation and use of explosive charges (e.g., Barclavite, Supernitrate and plastic nitrate with 40% aluminium) in roosting sites. However, it is difficult to place charges effectively or to burn when roosting occurs among canebrakes or in grassy places (Rachie and Majmudar, 1980). Further, burning kills most of the young but only 10% of the adults. As a result, some attempts to use toxic products have been tried. Spraying a 15-25% solution of parathion at a rate of 22.5-45 L/ha over the nesting sites with a light plane at night has given excellent results (Mallamaire, 1959).

Aerial spraying is a technique most widely used in Africa for *Quelea* control. With a well organized team and a skillful pilot, a success rate of about 75% for all spray sorties can be expected (Elliot, 1985). However, the aerial spray technique is encumbered by some problems. Apart from finding the roost or colony, two other important problems are posed by aerial spraying. The first is to decide when the target poses a genuine threat to crops and the second is to decide when the high cost of aerial spraying is justified. Elliot (1987) has also mentioned disadvantages of aerial spraying including the high cost of hiring an aircraft and the danger of environmental pollution. Such problems dictate use of integrated bird management strategies like the combination of bird-scaring by people with the implementation of as many agronomic techniques as possible.

2.2.6. ROLE OF PEARL MILLET VARIETIES IN RELATION TO BIRD DAMAGE

Despite the major efforts in bird resistance breeding in Uganda, no single character was observed to effectively reduce bird damage in sorghum (Doggett, 1988). In sorghum with long glumes, birds like weavers, which have powerful beaks, can squeeze the grain out of the glume. Elliot (1987) also discussed the problems with developing a cereal variety that will not be attacked by birds when they are hungry. Generally, birds attack cereals because of reduced availability of their natural foods. Further, despite sporadic attempts to develop resistant varieties over the last 30 years, no one has yet produced a variety which a bird will not eat when it has no choice. If birds do not eat the variety, it is also likely to be completely unpalatable to humans and their livestock.

The work on evolving varieties resistant to bird damage is of extreme importance since so far no effective methods for complete protection against damage have been developed. Beesley and Lee (1979) conducted an experiment with high tannin, bird resistant sorghum variety, Savannah 5, in an area in Botswana where *Quelea* regularly occurred and where no other sorghum was grown. Unprotected panicles yielded only 93 grains compared with 1,676 for protected ones, i.e., 94% crop loss was observed.

Several bristled cultivars of pearl millet available in India are thought to be relatively less susceptible to birds (Rachie and Majmundar, 1980). Beri et al. (1969) conducted a field trial in kharif 1967 at the Indian Agricultural Research Institute on four promising new pearl millet hybrids and observed that those with awns were less damaged by birds than those without awns. Further, one hybrid with panicles without awns was peculiar in that the grains on its panicles remain covered with a layer of dried anthers. This genotype had the lowest percentage of panicle damage and the lowest loss of grain, i.e., only 8.25%.

Plant height also has a role in crop protection. Dwarf cultivars seem less susceptible to bird attack in fields with taller varieties. Moreover, the shorter crop is more easily watched (ICAR, 1968).

2.3. THE EFFECT OF MAJOR GENES ON GRAIN AND STOVER YIELDS

2.3.1. GENERAL DESCRIPTION OF YIELD

Grain and stover yields of pearl millet are influenced by biotic and abiotic factors such as soil fertility, cultivar, date of sowing, rainfall, disease and pest prevalence. Prior to the development for pearl millet hybrid grain cultivars, grain yields were very low for this crop, averaging less than 400 kg ha^{-1} in both India and Africa (Rachie and Majmudar, 1980). Further, in the lower rainfall isohyets of Africa, grain yields obtained may be as low as 200-300 kg ha^{-1} whereas under better rainfall conditions productivity levels often range between 800-1200 kg ha^{-1}.

In India, depending on the climatic and soil conditions, pearl millet grain yields may range from less than 200 kg ha^{-1} in the sandy, semi-arid regions of central and western Rajasthan, to 300-400 kg ha^{-1} in the dry crop in the Deccan, up to 800-1000 kg ha^{-1} in Gujarat and Uttar Pradesh. Under irrigation, on-farm yields may rise to 1500-3000 kg

2.3.2. SOWING DATE AND YIELD

In unirrigated pearl millet growing areas, time of sowing has not been well studied because the crop must be sown with the advent of the rains. From an experiment in the Indian Agricultural Research Institute at New Delhi, Mahendra Pal (1973) recommended a sowing date for this area will be during the first to third week of July. In other parts of India, June-July is usually optimum for sowing dryland pearl millet except in the south, where rains are more favourable in October-November. Time of sowing for irrigated pearl millet crops in Gujarat is usually February.

However, sowing with the advent of rains has problems. Most Indian pearl millet cultivars are relatively early (less than 100 days seed to seed), with the result that early monsoon sowings are likely to be caught by heavy rains during flowering and seed set, with deleterious effects on grain yields and quality (Rachie and Majmudar, 1980). Further, the onset of the monsoon is often followed by a dry period of several days to 2-3 weeks and the developing seedlings could run out of moisture. Therefore, it is advisable to delay sowings until the onset of the monsoon is assured and thus to time maturation of the crop after the heavy rains are over.

The fact that farmers give more emphasis to variety earliness than grain yield may indicate their concern for grain yield stability and/or the need for earlier harvest than can be obtained under rainfed conditions by sowing late-maturing genotypes earlier. However, sowing time and variety choice should take into account the previous experience. If the crop matures too early, beyond the normal range of maturation time, yields and quality may be adversely affected by climatic conditions and/or bird damage.

In field experiments on different proso millet (*Panicum miliaceum* L.) varieties conducted during 1973-1977 at Sidney, Nebraska, USA, Nelson (1990) has reported that the earliest sowing delayed heading and decreased grain yield and plant height. Further, he observed sowing on 15 May or 1 June was best for grain yield and plant height. Later sowing (15 June and 1 July) resulted in lower yields and shorter plant height.

The growth, development and yield potentials of pearl millet can also be influenced by date of sowing. In Mexico, Maiti and Soto (1990) conducted trials on the growth, development and yield potentials of 15 genetically diverse pearl millet cultivars in 3 sowing dates (29 July, 15 or 27 August and 9 September). They reported that sowing date had a significant effect on the time required from emergence to panicle initiation (PI), from PI to 50% flowering, from 50% flowering to physiological maturity, time to flowering and yield components. Moreover, genotype x sowing date interactions were significant for most of the cultvars. From their observations, the 29 July sowing date resulted in the highest mean grain yield of 2.13 t ha^{-1} for the 15 cultivars. This could be attributed to the longer initial photoperiod (>13 h) delaying flowering until biomass production had reached a higher level.

A similar trial was conducted by Hawlader and Islam (1991) on foxtail millet (*Setaria italica* Linn.) varieties. They observed early sowing increased panicle length, resulting a higher yield than late sowing. However, early sowing didn't increase 1000-grain weight. On the other hand, in an experiment of 15 pearl millet cultivars sown on 3 sowing dates compared for grain filling periods, physiological maturity and 1000-seed weight, there were no significant difference among genotypes for grain filling period on any sowing date but highly significant differences among genotypes for 1000-grain weight (Maiti et al., 1995). Moreover, they observed a general pattern of prolonged grain filling periods with later sowing dates.

Sowing dates do not affect only pearl millet open-pollinated varieties, but can also affect pearl millet hybrid cultivars. Dhankar et al. (1982) conducted an experiment with 3 sowing dates and 3 plant populations to determine the optimum population and sowing date for two hybrids. They observed that the crop yielded significantly more grain when sown earlier than 15th July than when sown later. Further, the yield reductions for the two hybrids were 31 and 54.3 kg ha^{-1} per day of delayed sowing when sown 4 and 6 weeks late. Similarly, Singh and Singh (1983) had a trial on the effect of sowing date and technique on the growth and yield of hybrid pearl millet. They observed a maximum yield direct seeding with the onset of monsoon and a drastic reduction was observed thereafter. Increased panicle numbers in earlier sowing were responsible for higher grain yields while higher stover yields were associated with increased plant height and tiller numbers.

2.3.3. NITROGEN FERTILIZER APPLICATION AND YIELD

Some of the most limiting factors in crop production are the availability of nutrients and water. The same land is continuously farmed with nutrients being removed each season with the harvested crop. This becomes critical as many soils do not have large quantities of nutrients. Therefore, nitrogen fertilization is an important management consideration in the production of non-leguminous grain crops.

Soil fertility levels in relation to the production of pearl millet have been investigated in India. Rao and Nambiar (1952) have observed that fertilization offered great potential for improving grain yields, producing increases of 90% over unfertilized millet in an area of Tamil Nadu where irrigated pearl millet occupied 12.5% of the 1.5 million hectares of millets in 1952. In their observation, irrigated millet responded well to 67 and 101 kg of N ha^{-1}, plus up to 67 kg of P_2O_5 ha^{-1} and 56 kg of K_2O ha^{-1} on basal application of 11.2 Mt ha^{-1} of compost.

Mariakulandai and Morachan (1966) conducted an experiment on the response of local pearl millet to nitrogen fertilization. They observed that the pearl millet local variety had a good response to nitrogen application up to 101 kg ha^{-1} under irrigation and up to 45-67 kg ha^{-1} under rainfed conditions. Grain yield increases ranged from 6 to 74%, and a residual effect of up to 13.5% increase was sometimes obtained on millet following fertilized millet. Deosthale et al. (1972), conducted an experiment on the influence of the levels of N fertilizers on grain yield, grain protein and six essential amino-acids in five varieties of pearl millet. They observed an increase in the level of nitrogen from 0 to 120 kg N ha^{-1} increased grain yields significantly (2.48 t ha^{-1}). However, higher levels of fertilizer reduced grain yields to that obtained with 80 kg N ha^{-1} (2.05 t ha^{-1}).

The yield of pearl millet can be determined by the number productive tillers the plant produced. Mangath (1987) showed the interaction and associations between grain yield and its components at different nitrogen levels (0, 30, 60, 120 kg ha^{-1}) of white grain pearl millet. He reported grain yield increases with increased N application, mainly as a result of increases in the number of panicles, percentage grain set, grain weight and panicle length. Further, grain yield was positively correlated at all N levels with the number of productive tillers and percentage grain set.

The response of high yielding pearl millet varieties to nitrogen is not limited to areas with irrigation or high rainfall but occurs even under semi-arid conditions. Kumar and Sardana (1974) have clearly observed the superiority of hybrids and high-yielding varieties over locals at all levels of fertility, but particularly with high nitrogen fertilization. Uyoubisera (1988) conducted an experiment on pearl millet response to nitrogen fertilizer under different crop residue management practices on a semi-arid entisol and observed significant response up to 40 kg N ha^{-1} with a mean grain yield of 1.32 t ha^{-1}. However, further increase in fertilization rates did not increase yield appreciably.

The application of N levels vary for varieties and hybrids. In the arid region of India, in western Rajasthan, Joshi (1997) conducted an experiment on the response of millet-based cropping systems to nitrogen. He reported the N response of sole pearl millet varies with both millet variety and rainy season. Optimum N doses ranged from 23 kg ha^{-1} for local varieties to 84 kg ha^{-1} for hybrids. Moreover, his results suggested that as much as 24 kg N ha^{-1} could be used without seriously endangering pearl millet yields in drier years.

Applied nitrogen feritilizer can also increase total dry matter yields. In a trial conducted on four pearl millet cultivars from 1980 to 1985 at ICRISAT-Patancheru, the cultivars had different N response curves with total dry matter yields increasing significantly with applied N. The highest mean dry matter yield (3.26 t ha^{-1}) across nitrogen levels was observed from millet cultivar Ex-Bornu and the highest a mean dry matter yield of 3.35 t ha^{-1} across cultivars was observed with a fertilization rate of

40 kg N ha^{-1}. Nevertheless, the total dry matter yield observed for Ex-Bornu was 2.59 t ha^{-1} when N was not applied in the same season (ICRISAT, 1985).

2.3.4. THE INFLUENCE OF PEARL MILLET VARIETIES AND HYBRIDS ON YIELD

The yield of pearl millet varies from cultivar to cultivar (variety or hybrid). Maciel et al. (1995) evaluated the performance of pearl millet hybrids and open-pollinated cultivars in three trials sown during the 1986 rainy season in a semi-arid environment of Brazil. In trial 1, they observed there was highly significant variation among genotypes for flowering (41-53 days) and plant height (147-231 cm), but no significant variation for grain yield. In trial 2, genotypes did not show significant differences for the traits measured (panicle length, grain yield and stover yield) while in trial 3, there was highly significant variation among genotypes for panicle length (19-26 cm), grain yield and stover yield. Moreover, across the three trials the hybrids had mean grain yields ranging from 2.2 to 3.8 t ha^{-1} whereas the open-pollinated varieties produced a mean grain yield of 2.1 t ha^{-1}.

Efforts and resources have been directed towards the improvement of both open-pollinated varieties and hybrids so that crops grown from improved seed have better yield potential than local landrace varieties. Clegg (1996) indicated that yields of crops grown continuously on fields without added inputs will reduce each year. If any nutrient is limiting, neither genetic improvement of crop cultivars nor adequate water will be sufficient to increase yields. Moreover, the desired yield level and soil type will dictate the nutrients needed and the amount that will have to be applied. Adding nutrients to correct deficiencies will be required before yields can substantially improved by genetic means.

In southern Africa, an experiment was conducted on improved varieties and local landraces of pearl millet for their yield performance. Chintu et al. (1996) reported that the improved varieties out-yielded the local landraces and a mean grain yield of 1950 kg ha^{-1} was obtained.

A similar experiment was also conducted by Ipinge et al. (1996) on five improved open-pollinated varieties and one local landrace variety to assess short duration, drought resistant varieties with large, bold grains. They reported some of the improved varieties had the same qualities as the farmers' local, and in addition matured 3 weeks to 1 month earlier. These varieties can also be sown 1 month later than the locals and still provide some grain harvest for the family. Moreover, in the cropping seasons of 1992/93 and 1993/94, on-station yields of early-maturing improved cultivars like Okashana 1 were about 20 times higher than farmers' estimated pearl millet grain yields that ranged between 0.24 and 0.26 t ha^{-1}.

Varieties with the potential for a reasonable number of tillers can have an influence on the yield of the crop. Egharevba (1977) investigated the contribution of tiller numbers to the grain yield of pearl millet. He reported that reduced tiller number was associated with substantially increased grain yield. Maintaining three and five tillers per hill increased yield by about 20%. However, reducing to just one tiller per hill had a negative effect on yield. Reduced tiller number also had no advantage on the biological yield of the plant.

3.0. MATERIAL AND METHODS

Experiment 1

The main objective of the first experiment was to assess the effect of e_1 gene for photoperiod insensitivity early flowering on phenology and agronomic performance. This experiment was conducted on a total area of 0.5 ha at the Patancheru Campus of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (field RCE 24) at an altitude of 545 m.a.s.l. and latitude of 17° N. The soil type was sandy loam with limited water holding capacity and the field had low fertility status (following sorghum crop). The rainfall was mainly received during June to September and the total received during the growing season of sowing date one was 671.4 mm. The mean minimum and maximum temperatures were 21.1 and 30.7°C, respectively. This amount of rainfall was 53.8% (234.9 mm) above normal for the season. For sowing date two the total rainfall was 816.7 mm and the mean minimum and maximum temperatures were 20.7°C and 30.2°C, respectively. The rainfall was 74.5% (348.7 mm) more than normal for this period.

The nine open-pollinated genotypes of pearl millet used as experimental material in this study had open-pollinated variety ICMV 155 (Pheru Singh et al. 1994) as their common genetic background (Table 1).

There were two photoperiod treatments, two sowing dates, two levels of nitrogen side-dressing and nine genotypes. One of the photoperiod treatments was the normal day length (NDL) of Patancheru (17° N), which was initially 13.9 hours at the first sowing date and 13.7 hours at the second sowing date, and the other was an extended day length (EDL) treatment (14.7 hours at sowing) simulating the latitude of the Nagaur Agricultural Research Station of Rajasthan Agricultural University (27° N) in the northern part of the Indian pearl millet growing region. The EDL treatment was attained by using 100W incandescent bulbs suspended above the crop on a 3 m x 5 m grid. The light was operated by an automatic time clock, during both the predawn (5:12-7:00 am) and post-sunset hours (5:00-7:48 pm). This treatment started 10 days after sowing, i.e., while plants were still in the juvenile phase (Ong and Everard, 1979) and ended 71 days after sowing, by which time all plants had initiated panicle development.

During the first sowing date, the nine genotypes were mechanically sown on June 25, 1998 for both the NDL and EDL treatments. Following sowing the plots were furrow irrigated to ensure uniform germination. The crop was subsequently grown under rainfed conditions. The second sowing date, 15 days later, was partially hand sown (EDL) and partially mechanically sown (NDL) after rain due to operational problem. The hand-sown portion faced bird problems (seedlings were destroyed at emergence by grey partridges *Fracolinus pondicerianus*) and the machine-sown portion had crusting and compaction problems that were resolved to some extent by giving one irrigation to the whole experiment.

To upgrade the fertility status of the soil, the entire plot was fertilized with DAP and urea. DAP was applied at a rate of 100 kg ha^{-1} (46 kg P_2O_5 + 18 kg N) before sowing as a basal application (N1 and N2 treatments) and urea was then applied at a rate of 100 kg ha^{-1} (46 kg N) as a top dressing 20 days after sowing (N2 treatment only). During the early growth stages of the crop, some necessary cultural practices were carried out. Two weeks after emergence of the seedlings, they were hand thinned to a within-row spacing of 15 cm to maintain a uniform stand of 110,000 plants per hectare. Subsequent interculturing and earthing-up operations were done mechanically. The experimental design used was a split-split-split plot design with three replications (see Figure 1a, 1b and Annex 1). The NDL and EDL were allotted to the main plots, the two sowing dates to the sub-plots, the two fertilization levels (N1 and N2) to the sub-sub plots and the 9 genotypes to the sub-sub-sub plots. The gross size of each plot was 9.6 m^2 (4 m x 4 rows x 0.6 m) and each plot was bordered at either end by a 1 m path. The net harvested plot size was 4.2 m^2 (3.5 m x 2 rows x 0.6 m).

Table 1. Pearl millet genotypes used in this study

No. and Name	Pedigree	Status	Seed lot
1. ICMV 155	ICMV 84400 Bred by random mating (RM) S_1 progenies of 59 S_0 plants of NELC C4 mass selected at Patancheru in the 1984 rainy season (Pheru Singh et al., 1994)	-	BM 25C/K97
2. ICMV 155 TCP	Top-cross pollinator version of ICMV 155 bred by RM 46 progenies selected based on testcross hybrid performance at Gwalior & Patancheru in the 1995 rainy season (K95)	SYN 0	RP 5B/S96
3. ICMV 155 *bmr*	ICMV 155 *bmr/bmr* brown midrib version, bred by RM 88 BC_6F_2 brown midrib progenies	SYN 0	BUS 13A/K97
4. ICMV 155 *Bmr*	ICMV 155 *Bmr/Bmr* green (normal) midrib version, bred by RM 823 BC_6F_2 uniformly normal green progenies	SYN 0	BUS 12C/K97
5. ICMV 155 Bristled	ICMV 155 long bristled version, bred by RM 97 uniformly bristled BC_7F_3 progenies having ICMP 451 (Anand Kumar, 1995) as doner	SYN 0	BUS 6A/K97
6. ICMV 155 e_le_l	ICMV 155 early e_l/e_l version, bred by RM 91 early flowering BC_6F_3 progenies selected in an Extended Day Length Nursery (EDLN) RP 10A/K97	SYN 0	BM 1/S98
7. ICMV 155 E_lE_l	ICMV 155 E_l/E_l version, bred by RM 283 uniformly late flowering BC_6F_2 progenies selected in EDLN RP 10A/K97	SYN 0	BS 3C/R97
8. ICMV 155 early	Bred by RM 213 S_1 progenies from early-flowering S_0 plants selected from a bulk of ICMV 155 grown under extended-day length conditions in EDLN RCE 24/LK97	SYN 0	BM 21/S98
9. ICMV 155 late	Bred by RM 189 S_1 progenies from late-flowering S_0 plants selected from a bulk of ICMV 155 grown under extended-day length conditions in EDLN RCE 24/LK97	SYN 0	RL 33/S98

Fig. 1a. Plots under normal day length

Fig. 1b. Plots under extended day length

In this experiment some protection measures were taken against birds, weeds and insect pests. Plots were protected from bird damage using bird scarers from 6:00 am in the morning until 7:00 pm in the evening from early grain fill of the earliest-maturing plot until harvest of the latest-maturing plot. Weeds, primarily *Cyperus rotundus* and annuals grasses, were controlled by interculture and two hand weedings. Endosulfan 35% EC was sprayed once at a rate of 2 Lt ha^{-1} to control cotton grey weevil (*Mylloceris* spp.) when leaf damage was estimated at 10-15% (ICRISAT Farm Services Crop Protection Section). *Pyricularia* leaf spot (blast) (*Pyricularia grisea)* was observed in the second sowing date but the damage was not severe.

Observations and measurements in Experiment 1

Observations and measurements taken during the growing seasons were as follows.

1. Bloom: Time to 75% flowering was recorded for the 2 two central rows of each plot as the number of days from sowing until 75% of the plants produced stigmas on their main stem panicles.
2. Plant count: Before counting and subsequent harvest operations, 0.25 m was cut from both ends of the central two rows of each plot resulting in 3.5 m length of each row. The number of plants in these two shortened rows was then recorded without considering the tillers as separate plants.
3. Plant height: Plant height was measured from the base of the stem to the tip of the panicle at harvest stage. It was done on 5 sample plants from the two central two rows of each plot.
4. Panicle count: At the time of harvest, panicles from the two central rows of each plot were counted.
5. Panicle yield: After harvesting was completed, panicles were put in an oven for 24 hours and dried at a temperature of 60°C. The dry weight of the panicles was then recorded before threshing.
6. Grain yield: Panicles were threshed and cleaned. The weight of the grain from each plot was recorded.

7. Total dry matter: After panicles were harvested, the stems and the tillers were cut for biomass analyses from the middle two rows of the whole replications of the two sowing dates. Fresh weights of the biomass were first taken and samples were then collected from each entry and chopped and fresh weights of these samples were taken. The chopped samples were put in a drier for 2 days at a temperature of 60°C and their dry weights were then recorded.

Experiment 2

The second experiment was conducted to assess the effectiveness of long panicle bristles in reducing grain yield losses to birds. Bird damage was expected to be reduced by back cross introduction of a single dominant gene from ICMP 451 (Anand Kumar et al., 1995) for long, large and stiff panicle bristles (awns) (see Fig. 2). The portion of this experiment without bird scarers was conducted in a separate field at ICRISAT's Patancheru campus (RP 2A), on a total effective area of 0.052 ha where there was heavy bird pressure (see Fig. 3). The nine genotypes used in Experiment 1 (Table 1) were also used in this experiment. The total amounts of rainfall and mean minimum and maximum temperature observed during the growing season of sowing date one of this second experiment were the same as sowing date one of Experiment 1. In the case of sowing date two of this second experiment, the total amount of rainfall received was 734.2 mm, which was 80.7% (328 mm) more than the normal in this period. The average minimum and maximum temperatures were 20.8°C and 30.3°C, respectively. The minor differences in rainfall and temperatures in the second sowing date of this experiment in RP 2A compared to RCE 24, were due to the earlier harvest (16 days) of this portion of the experiment. The soil type of the field was loam. This field had a higher fertility status than RCE 24 because it was sown to groundnut and cowpea (a green manure crop) in the previous rabi (post-rainy season) and kharif (rainy season) growing seasons, respectively. The gross and net plot sizes used were the same as in Experiment 1.

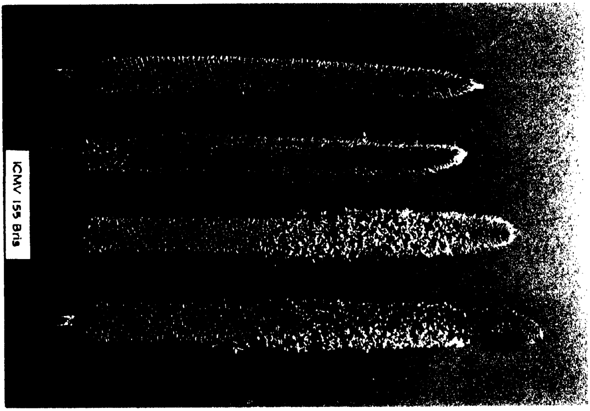

Fig. 2. The ICMV 155 Bristled genotype

Fig. 3. Roseringed parakeets (*Psittacula krameri*) arriving to feed on the pearl millet field without bird scarers in Experiment 2, Patancheru rainy season 1998.

This experiment was conducted in a split-split plot design with 3 replications (Annex 2). In this case, the main plots were +/- bird scaring, with the "+ bird-scaring" main plot being the N2 (i.e., side-dressed) portion of the normal day length main plot of Experiment 1 described above and the "– bird-scaring" main plot being located in a different field (RP 2A) sown on the same two dates as the first experiment. The sub-plots were the two sowing dates, the sub-sub plots were the nine genotypes.

Agronomic practices used in this second experiment were the same as in the N2 portion of experiment one except that spraying of pesticide against the cotton gray weevil was not required. The common weeds in this experiment were annuals that were controlled by two hand weedings and one interculturing/earthing-up operation.

Observations and measurements in Experiment 2

Bloom, plant count, total dry matter, plant height, panicle count, panicle yield and grain yield observations and measurements were done as in Experiment 1.

Statistical Analysis

Analysis of Variance

Analysis of variance was computed using GenStat 5 (1993) soft ware in both experiments. Analysis was done for plant height, total dry weight of biomass, time to 75% bloom, grain yield, panicle number per plot, panicle yield and plant number per plot.

4.0. Results

The results of the two experiments after analysis are shown below with their respective ANOVA tables and comparison of treatment means using L.S.D.

4.1. Results of Experiment 1

The main objective of the first experiment was to determine the effect of the e_l gene on flowering time and yield components, and compare the effect of its backcross transfer into the ICMV 155 background (genotype 6 = ICMV 155 e_l e_l with a single cycle of modified mass selection (genotype 8 = ICMV 155 early). The normal and extended day length treatments were assigned to the main plots, two sowing dates to the sub-plots, two N side-dressing rates (+/-) to sub-sub-plots, and the nine genotypes to the sub-sub-sub-plots. Analysis of variance for this experiment are shown as follows in Table 1.1, 1.3, 1.5, 1.9, 1.13, 1.14 and 1.16, accompanied by L.S.D. comparisons of genotypes when the ANOVA indicates significant genotype differences. As indicated in Table 1.1 by the percentage of the sums of squares accounted for the most important source of variation in grain yield in this experiment was nitrogen side-dressing treatments (46%) followed at a distance by sowing dates (18%), and genotypes (6%) with replications and the various residual terms accounting for another 19% of the total sums of squares for this trait.

Table 1.1: Analysis of variance of grain yield (kg ha^{-1}) in Experiment 1.

Source of variation	d.f.	S.S.			v.r.	F pr.
Rep stratum	2	2.225E+06	2%	1.112E+06	1.87	
Rep.Photopd stratum						
Photopd	1	7.565E+05		7.565E+05	1.27	0.376 NS
Residual	2	1.188E+06	1%	5.941E+05	0.68	
Rep.Photopd.Sdate stratum						
Sdate	1	1.883E+07	18%	1.883E+07	21.51	0.010 *
Photopd.Sdate	1	1.199E+05		1.199E+05	0.14	0.730 NS
Residual	4	3.502E+06	3%	8.755E+05	4.11	
Rep.Photopd.Sdate.N stratum						

N	1	4.670E+07	46%	4.670E+07	219.04	<.001	***
Photopd.N	1	1.605E+05		1.605E+05	0.75	0.411	NS
Sdate.N	1	3.280E+06	3%	3.280E+06	15.38	0.004	**
Photopd.Sdate.N	1	1.292E+05		1.292E+05	0.61	0.459	NS
Residual	8	1.706E+06	2%	2.132E+05	2.57		
Rep.Photopd.Sdate.N.Geno stratum							
Geno	8	6.260E+06	6%	7.825E+05	9.43	<.001	
Photopd.Geno		9.906E+05		1.238E+05	1.49	0.166	NS
Sdate.Geno		1.389E+06	1%	1.736E+05	2.09	0.041	*
N.Geno		1.255E+06		1.568E+05	1.89	0.066	NS
Photopd.Sdate.Geno		4.226E+05		5.283E+04	0.64	0.746	NS
Photopd.N.Geno		7.406E+05		9.258E+04	1.12	0.357	NS
Sdate.N.Geno		1.281E+06		1.601E+05	1.93	0.060	NS
Residual	136	1.129E+07	11%	8.299E+04			
Total	215	1.022E+08					

Table 1.2a: Ranked genotypes of grain yields (kg ha^{-1}) of the nine near-isogenic pearl millet genotypes in sowing date x genotypes interactions (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 $e_l e_l$, 7 = ICMV 155 $E_l E_l$, 8 = ICMV 155 early, 9 = ICMV 155 late; SD1 = sowing date one: 25 June, SD2 = sowing date two: 9 July); Patancheru, RCE 24, rainy season 1998.

Rank	SD1	SD2
1	5(1824)	2(1171)
2	8(1790)	9(1144)
3	9(1698)	5(1107)
4	**6(1671)**	8(1057)
5	1(1572)	4(1026)
6	2(1555)	**6(939)**
7	7(1448)	1(835)
8	4(1426)	3(738)
9	3(1085)	7(737)
Mean	1563	973

L.S.D. = 354

Table 1.2b: The interaction of sowing date and nitrogen side-dressing treatments on grain yield (kg ha^{-1}).

Sowing date	N1	N2
1	975	2151
2	631	1314

L.S.D. = 347

Grain Yield

In the analysis of variance for grain yield (Table 1.1), there was no significant variation ($P = 0.376$) for photoperiod showing that mean grain yield response for the normal and extended day lengths were not different. There was a significant difference ($P = 0.010$) between the two sowing dates indicating that sowing dates had influenced grain yield. The interaction of photoperiod and sowing dates was not significant ($P = 0.730$) for grain yield. The mean grain yield across day length treatments in the first sowing date (25 June, 1998) was 1563 kg ha^{-1} (Table 1.2a), which was significantly greater than the 973 kg ha^{-1} observed in the second sowing date (9 July, 1998). This could be attributed to some combination of soil crusting and compaction, leaching of basal fertilizer, and shorter daily duration of photosynthetically active radiation in the second sowing date.

For the nitrogen (N) side-dressing treatments, there was a highly significant difference ($P < 0.001$) in mean grain yields obtained from the two rates of N side-dressing. The interaction of photoperiod and N treatments was not significant ($P = 0.411$) for grain yield. However, there was a highly significant ($P = 0.004$) interaction between sowing dates and N side-dressing rates for grain yield, showing that variation in sowing dates with N treatments had influenced grain yield in a non-additive manner (Table 1.2b).

The three-way interaction between photoperiods, sowing dates and N side-dressing rates was not significant ($P = 0.459$). Further analysis for grain yield variation due to genotypes was done. The nine genotypes showed highly significant differences ($P < 0.001$) for grain yield.

The interaction between photoperiods and genotypes was not significant ($P = 0.166$) for grain yield. However, the interaction between sowing dates and genotypes was significant for this trait, indicated that sowing dates and genotypes interacted in a non-additive manner to influence grain yield (Table 1.2a). The interaction of N side-dressing rates and genotypes was not significant ($P = 0.066$) for grain yield showing that there was no yield variation induced by the interaction of these two factors.

The three-way interaction of photoperiods, sowing dates and genotypes was not significant (P = 0.746) for grain yield. Similarly, the interaction of photoperiods, N side-dressing rates and genotypes was not significant (P = 0.357) for this trait. Finally, the interaction of sowing dates, N side-dressing rates and genotypes was not significant (P = 0.060) for grain yield.

Comparison of grain yield of ICMV 155 $e_l e_l$ (genotype 6) with the other genotypes (Table 1.2a) was made using L.S.D. (354). In the first sowing date (25 June), grain yield of ICMV 155 $e_l e_l$ was not significantly different from any other genotype except the lowest yielding one, ICMV 155 *bmr*. In the second sowing date, the mean grain yield of ICMV 155 $e_l e_l$ across photoperiods and N side-dressing rates was not significantly different from that of any other tested genotype.

Moreover, comparison of grain yield (Table 1.2b) was made using L.S.D. (347) for the interaction of sowing dates and N side-dressing rates. In low fertility (N1), there was no significant difference between the two sowing dates, but in the high fertility treatment (N2) there was a significant difference between the two sowing dates.

Table 1.3: Analysis of variance of total dry matter yield (t ha^{-1}) in Experiment 1.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	10.9188	1%	5.4594	0.72	
Rep.Photopd stratum						
Photopd	1	210.5930	16%	210.5930	27.67	0.034 *
Residual	2	15.2223	1%	7.6111	0.60	
Rep.Photopd.Sdate stratum						
Sdate	1	307.1611	23%	307.1611	24.03	0.008 **
Photopd.Sdate	1	0.7960		0.7960	0.06	0.815 NS
Residual	4	51.1199	4%	12.7800	6.09	
Rep.Photopd.Sdate.N stratum						
N	1	490.2960	37%	490.2960	233.46	<.001 ***
Photopd.N	1	2.4394		2.4394	1.16	0.313 NS
Sdate.N	1	50.6033	4%	50.6033	24.10	0.001 **
Photopd.Sdate.N	1	1.1966		1.1966	0.57	0.472 NS
Residual	8	16.8011	1%	2.1001	3.24	
Rep.Photopd.Sdate.N.Geno stratum						
Geno	8	30.3452	2%	3.7932	5.85	<.001 ***

Photopd.Geno	8	4.4528	0.5566	0.86	0.553 NS
Sdate.Geno	8	7.2983	0.9123	1.41	0.199 NS
N.Geno	8	12.0412	1% 1.5051	2.32	0.023 *
Photopd.Sdate.Geno	8	2.0475	0.2559	0.39	0.922 NS
Photopd.N.Geno	8	5.9793	0.7474	1.15	0.333 NS
Sdate.N.Geno	8	9.5625	1.1953	1.84	0.074 NS
Residual	136	88.1967	7% 0.6485		
Total	215	1317.0708			

Table 1.4: Ranked genotypes of total dry matter yield (t ha^{-1}) of the nine near-isogenic pearl millet genotypes and their interaction with nitrogen side-dressing treatments (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_le_l, 7 = ICMV 155 E_lE_l, 8 = ICMV 155 early, 9 = ICMV 155 late; N1 = nitrogen treatment 1 (- side-dressing), N2 = nitrogen treatment 2 (+ side-dressing); Patancheru, RCE 24, rainy season 1998.

Rank	N1	N2	N2-N1
1	8(3.53)	7(7.09)	7(3.59)
2	7(3.50)	2(6.88)	2(3.55)
3	9(3.48)	4(6.67)	4(3.36)
4	2(3.33)	5(6.45)	5(3.36)
5	4(3.31)	9(6.43)	9(2.95)
6	1(3.31)	8(6.35)	8(2.82)
7	5(3.09)	1(6.04)	1(2.73)
8	**6(3.01)**	3(5.64)	3(2.67)
9	3(2.97)	**6(5.07)**	**6(2.06)**
Mean	3.28	6.29	1.47

L.S.D = 0.73

Total Dry Matter Yield

In the analysis of variance for total dry matter yields (t ha^{-1}) (Table 1.3), there was a significant difference (P = 0.034) between the two photoperiod treatments. This implied that there was a difference in crop growth duration between the normal and extended day lengths since the artificial lighting intensity used was not enough to cause significant photosynthesis. There was a highly significant difference (P = 0.008) between the two sowing dates for total dry matter yield. Further, the interaction of the sowing dates with photoperiods was not significant (P = 0.815) for total dry matter yield showing that the variation in day length and sowing time treatments did not affect biomass yield in a non-additive manner.

When nitrogen side-dressing treatments (+/-) were considered, there was a highly significant difference ($P < 0.001$) for the total dry matter yields. This indicated that the nitrogen side-dressing treatments influenced total biomass production. There was no significance interaction between the nitrogen and photoperiod treatments ($P = 0.313$) for total dry matter yields indicating that the variation in day length and nitrogen side-dressing did not synergistically influence total dry matter yields, and instead exerted independent influences on this trait. The interaction of sowing date and nitrogen treatments was highly significant ($P = 0.001$) for total dry matter yield showing that the two sowing dates and nitrogen side-dressing treatments together had a non-additive influence on plant growth.

The three-way interaction between photoperiod, sowing date and nitrogen side-dressing treatments, was not significant ($P = 0.472$) indicating that variation in day length, time of planting and nitrogen side-dressing rate did not contribute to the variation in biomass yields in a non-additive manner.

When the genotypes were evaluated for their total dry matter yields, highly significant ($P < 0.001$) genotypes effects were observed. The interaction between photoperiod and genotype was not significant ($P = 0.553$) for total dry matter yields. Similarly, the interaction of sowing date and genotype was not significant ($P = 0.199$) for this character. This implied that the effects of variation in day length and sowing date were additive to those of genotypes for total dry matter yields. However, the interaction of nitrogen side-dressing and genotype treatments was significant ($P = 0.023$) implying that genetic differences in response to the rates of nitrogen side-dressing could have influenced plant growth.

There was no significant three-way interaction ($P = 0.922$) between photoperiod, sowing date and genotype treatments for total dry matter yields. Moreover, the interaction between photoperiod, nitrogen and genotype treatments was also not significant (P = 0.333) for this character. Finally, the interaction between sowing date, nitrogen and genotype treatments was not significant (P = 0.074) for total dry matter yields. Therefore the effects of three-way interactions involving genotype and each of the three possible pairs of the other three groups of treatments in this experiment were not large enough to be of concern. None of these three-way interactions accounted for as much as 1% of the total sum of squares for this trait in this experiment (Table 1.3).

Comparison of ranked genotype means for total dry matter yield in the two nitrogen side-dressing treatments (+ and -) showed that ICMV 155 early and ICMV 155 Bristled contributed the most to the significant genotype x nitrogen side-dressing treatment interaction (Table 1.4). Possible reasons for this are not immediately obvious.

Comparison of total dry matter yield of the ICMV 155 e_1e_1 genotype with the other genotypes was made (Table 1.4) in each nitrogen side-dressing treatments separately using L.S.D. (0.73). It was observed that the ICMV 155 e_1e_1 early genotype was not significantly lower yielding than others for total dry matter under low soil fertility conditions (N1), where there were no statistically significant differences between any of the genotypes for this trait. This implied that the ICMV 155 e_1e_1 genotype was not more sensitive than others to these low soil fertility conditions. However, under the high soil fertility treatment (N2), the ICMV 155 e_1e_1 genotype had significantly lower total dry matter yields than all other genotypes except ICMV 155 *bmr* indicating that it did not have as great capacity as other genotypes to respond to more favorable conditions. When N1 and N2 was compared, the mean total dry matter yield of N2 (+ side dressing) was significantly greater than N1 (- side-dressing) (6.29 to 3.28 t ha^{-1}).

Further, the difference between the two nitrogen applications (N2 – N1) was computed (Table 1.4). The biggest difference was observed by the genotypes ICMV 155 E_1E_1 and ICMV 155 TCP, indicating that these genotypes were the ones most responsive to the soil fertility differences. The smallest difference was observed for the early genotype ICMV 155 e_1e_1, which implied that this genotype was the least responsive (most insensitive) to soil fertility differences. However, ICMV 155 e_le_l was significantly less responsive to improved soil fertility only compared to ICMV 155 E_lE_l and ICMV 155 TCP.

Table 1.5: Analysis of variance for time to 75% flowering (d) in Experiment 1.

Source of variation	d.f.	s.s.	%SS	m.s.	v.r.	F pr.
Rep stratum	2	222.250	2%	111.125	5.27	
Rep.Photopd stratum						
Photopd	1	1335.042	12%	1335.042	63.28	0.015 *
Residual	2	42.194	0%	21.097	0.17	
Rep.Photopd.Sdate stratum						
Sdate	1	3642.449	33%	3642.449	29.45	0.006 **
Photopd.Sdate	1	16.116		16.116	0.13	0.736 NS
Residual	4	494.741	4%	123.685	3.84	
Rep.Photopd.Sdate.N stratum						
N	1	1227.894	11%	1227.894	38.16	<.001 ***
Photopd.N	1	13.005		13.005	0.40	0.543 NS
Sdate.N	1	9.375		9.375	0.29	0.604 NS
Photopd.Sdate.N	1	3.375		3.375	0.10	0.754 NS
Residual	8	257.407	2%	32.176	5.55	
Rep.Photopd.Sdate.N.Geno stratum						
Geno	8	2699.417	24%	337.427	58.16	<.001 ***
Photopd.Geno	8	108.583	1%	13.573	2.34	0.022 *
Sdate.Geno	8	106.509	1%	13.314	2.29	0.024 *
N.Geno	8	106.065	1%	13.258	2.29	0.025 *
Photopd.Sdate.Geno	8	14.343		1.793	0.31	0.962 NS
Photopd.N.Geno	8	43.120		5.390	0.93	0.495 NS
Sdate.N.Geno	8	32.083		4.010	0.69	0.699 NS
Residual	136	788.991	7%	5.801		
Total	215	11162.958				

Table 1.6: Ranked genotypes of times to 75% flowering (d) of the nine near-isogenic pearl millet genotypes and their interaction with photoperiod treatments (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_le_l, 7 = ICMV 155 E_lE_l, 8 = ICMV 155 early, 9 = ICMV 155 late, Initial photoperiods: Normal = 13.9 h, Extended = 14.7 h); Patancheru, RCE 24, rainy season 1998.

Rank	Normal	Extended
1	**6(49.33)**	**6(50.83)**
2	5(52.50)	5(58.08)
3	2(53.67)	9(58.50)
4	9(54.17)	8(58.75)
5	8(54.25)	2(59.08)
6	1(55.00)	1(61.00)
7	4(56.42)	4(61.25)
8	3(58.92)	7(65.42)
9	7(59.50)	3(65.58)
Mean	54.9	59.8

L.S.D. = 2.34

Table 1.7: Ranked genotypes of times to 75% flowering (d) of the nine near-isogenic pearl millet genotypes and their interaction with sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; SD1 = sowing date one: 25 June, SD2 = sowing date two: 9 July); Patancheru, RCE 24, rainy season 1998.

Rank	SD1	SD2
1	**6(44.75)**	**6(55.42)**
2	8(51.58)	5(58.92)
3	5(51.67)	9(60.08)
4	2(52.00)	2(60.75)
5	9(52.58)	8(61.42)
6	1(53.33)	4(62.58)
7	4(55.08)	1(62.67)
8	3(58.92)	3(65.58)
9	7(59.25)	7(65.67)
Mean	53.24	61.45

L.S.D. = 4.14

Table 1.8: Ranked genotypes of times to 75% flowering (d) of the nine near-isogenic pearl millet genotypes and their interaction with nitrogen side-dressing treatments (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; N1 = no side-dressing, N2 = side-dressing applied;) Patancheru, RCE 24, rainy season 1998.

Rank	N1	N2
1	**6(51.08)**	**6(49.08)**
2	5(58.17)	5(52.42)
3	9(58.83)	2(53.58)
4	8(59.17)	8(53.83)
5	2(59.17)	9(53.83)
6	1(59.25)	4(55.67)
7	4(62.00)	1(56.75)
8	3(64.92)	3(59.58)
9	7(65.00)	7(59.92)
Mean	59.73	54.96

L.S.D. = 2.43

Times to 75% flowering

The analysis of variance for time to 75% flowering (Table 1.5) showed significant contribution to the observed variation from the photoperiod ($P = 0.015$), sowing date ($P = 0.006$), and nitrogen side-dressing ($P < 0.001$) treatments. Moreover, the interactions between these three groups of treatments were not significant for time to 75% flowering, implying that these treatments had independent effects on this trait.

There were highly significant ($P < 0.001$) effects of the genotypes in this experiment on observed variation in flowering time. This indicated that the time required to reach 75% flowering differed from genotype to genotype.

The interaction of photoperiod and genotype treatments was significant ($P = 0.022$) for time to 75% flowering. This indicated that the genotypes did not all respond to the two photoperiod treatments in the same way. This is easily observed in Table 1.6 where photoperiod-insensitive genotype ICMV 155 e_1e_1 was much less responsive to the extended day length treatment having a flowering delay of 1.5 d over the normal day length treatment as compared to 4.3 to 6.6 d flowering delay in respond to the extended day lengths for the other eight genotypes studied. Further, the interaction of sowing dates and genotypes was significant ($P = 0.024$) for time to 75% flowering. This indicated that the genotypes did not all respond to sowing date treatments in the same manner. This is seen in Table 1.7 where the difference in flowering time between ICMV 155 e_1e_1 and ICMV 155 Bristled was much greater in sowing date 1, which had a longer photoperiod than sowing date 2. Thus photoperiod insensitivity of ICMV 155 e_1e_1 has again caused this genotype to contribute significantly to this interaction. The small rank cross-over of genotypes 8 (ICMV 155 early) and 9 (ICMV 155 late) may also have contributed to the significance of this interaction, but it is difficult to explain why this occurred except perhaps that the selection procedures employed in developing these two entries were ineffective and this rank changes is the result of random variation.

Genotype x nitrogen interaction was significant (P = 0.025) for time to 75% flowering. Once again, this indicted the genotypes responded differently to the nitrogen side-dressing treatments. Further, the ICMV 155 e_le_l genotype was less adversely affected (in terms of delayed flowering) than other entries when it received no nitrogen side-dressing (Table 1.8). Thus the e_le_l homozygote is not only less sensitive to extended photoperiod, but also appears to be less sensitive to nitrogen deficiency, at least in terms of flowering time. There were no important rank change genotype x nitrogen treatment interactions, despite statistical significance of the interaction.

None of the three-way interactions between treatments were significant for the time to 75% flowering (Table 1.5)

Comparison of ICMV 155 e_le_l, the earliest flowering entry, with the rest of the genotypes was made within photoperiod treatments using L.S.D. (2.34 d) for the character time to 75% flowering (Table 1.6). Under both extended and normal day lengths, ICMV 155 e_le_l was significantly earlier to flower than all eight other genotypes in this study.

Across genotypes (Table 1.6), the mean flowering time in the normal day length treatment was about 5 days less than for the extended day length treatment (54.9 to 59.8). Thus, day length had an influence on the time to 75% flowering of most genotypes. In fact, photoperiod treatments accounted for 12% of the observed variation in flowering time in this experiment (Table 1.5).

Further, comparison of ICMV 155 e_le_l, the earliest flowering genotype was made with the rest of the genotypes within sowing dates using L.S.D. (4.14 d) for the time to 75% flowering (Table 1.7). ICMV 155 e_le_l was significantly earlier than other genotypes in both sowing dates except in case of ICMV 155 Bristled in sowing date 2. The major source of G x SD interaction was associated with more delayed flowering of all genotypes except ICMV e_le_l (genotype 6) in SD2 compared to SD1. This is not an expression of reduced sensitivity of genotype 6 (ICMV 155 e_le_l) to longer the normal day length in SD1 but perhaps instead reflects the lesser sensitivity of ICMV 155 e_le_l to the lower fertility in sowing date 2 as a result of leaching of basal fertilizer by the unusual high rainfall. As the two sowing dates were compared (Table 1.7), sowing date 1 required less time to reach 75% flowering than those in sowing date 2 (53.24 Vs 61.45 d).

Moreover, comparison of ICMV 155 e_le_l with the rest of the genotypes was made (Table 1.8) using L.S.D. (2.434 d). The early gene e_l also confers insensitivity to N-deficiency for time to 75% flowering, which contributes to the G x N interaction. There is no important sources of rank-change G x N interaction for time to 75% flowering, despite statistical significance of the interaction. When N1 and N2 were compared, the time required for 75% flowering was less in N2 than N1 (54.96 to 59.73 d). This implied that improving soil fertility by application of a nitrogen side-dressing contributed to reducing flowering time.

Table 1.9: Analysis of variance for plant height (cm) in Experiment 1.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	3718.3	3%	1859.1	5.01	
Rep.Photopd stratum						
Photopd	1	142326.8	36%	142326.8	383.58	0.003 **
Residual	2	742.1	0%	371.1	0.13	
Rep.Photopd.Sdate stratum						
Sdate	1	83677.8	21%	83677.8	28.35	0.006 **
Photopd.Sdate	1	5689.8		5689.8	1.93	0.237 NS
Residual	4	11808.3	3%	2952.1	2.90	
Rep.Photopd.Sdate.N stratum						
N	1	72065.7	18%	72065.7	70.83	<.001 ***
Photopd.N	1	128.5		128.5	0.13	0.731 NS

Sdate.N	1	22542.1	6% 22542.1	22.16	0.002	**
Photopd.Sdate.N	1	11.3	11.3	0.01	0.919	NS
Residual	8	8139.5	2% 1017.4	7.14		
Rep.Photopd.Sdate.N.Geno stratum						
Geno	8	11256.4	3% 1407.0	9.87	<.001	***
Photopd.Geno	8	5501.3	1% 687.7	4.83	<.001	***
Sdate.Geno	8	1720.6	215.1	1.51	0.159	NS
N.Geno	8	3524.1	1% 440.5	3.09	0.003	**
Photopd.Sdate.Geno	8	1408.7	176.1	1.24	0.283	NS
Photopd.N.Geno	8	1632.4	204.0	1.43	0.189	NS
Sdate.N.Geno	8	2857.4	1% 357.2	2.51	0.014	*
Residual	136	19378.3	5% 142.5			
Total	215	398129.0				

Table 1.10: Ranked genotypes of mean plant heights in the interaction of photoperiod (normal and extended day lengths) and genotypes (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 $e_l e_l$, 7 = ICMV 155 $E_l E_l$, 8 = ICMV 155 early, 9 = ICMV 155 late); Patancheru, RCE 24, rainy season 1998.

Rank	Normal	Extended
1	2(175)	7(238)
2	7(174)	4(234)
3	9(173)	9(223)
4	3(169)	8(222)
5	4(169)	5(222)
6	1(168)	3(221)
7	5(168)	1(219)
8	8(167)	2(218)
9	**6(163)**	**6(192)**
Mean	169.5	220.8

L.S.D. = 10.82

Table 1.11: Ranked genotypes of mean plant heights in the interactions of sowing dates, nitrogen and genotypes (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 $e_l e_l$, 7 = ICMV 155 $E_l E_l$, 8 = ICMV 155 early, 9 = ICMV 155 late; sowing dates: SD1 = 25 June, SD2 = 9 July, Nitrogen side-dressing treatments: N1 = -, N2 = +); Patancheru, rainy season 1998.

	SD1		SD2	
Rank	N1	N2	N1	N2
1	1(193)	7(271)	7(177)	2(194)
2	3(189)	4(257)	4(174)	3(188)
3	4(188)	9(247)	3(173)	7(187)
4	5(188)	2(247)	9(170)	8(187)
5	9(188)	5(244)	8(166)	5(187)
6	7(188)	1(239)	2(165)	9(186)
7	8(187)	8(238)	1(164)	4(185)
8	2(182)	3(231)	5(160)	1(178)
9	**6(174)**	**6(216)**	**6(160)**	**6(161)**
Mean	186.3	243.3	167.4	183.5
G.mean	214.8		175.5	

L.S.D. 22.73

Mean N1 = 177
Mean N2 = 213

Mean Plant Heights

Main effects of photoperiod (36%), sowing date (21%), and nitrogen side-dressing (18%) treatments accounted for most of the observed variation in plant height in this experiment (Table 1.9), and all were highly significant. In the analysis of variance, there was a highly significant ($P = 0.003$) effect of photoperiod. The mean plant height in the normal day length treatment averaged 50 cm less than that observed in the extended day length treatment (Table 1.10). Similarly, there was a highly significant ($P = 0.006$) effect of sowing date treatments on this trait. There was no significant interaction between sowing date and photoperiod treatments ($P = 0.237$) for plant height.

When the nitrogen side-dressing treatments were compared, there was highly significant ($P < 0.001$) effect for plant height and a highly significant interaction of nitrogen side-dressing and sowing date treatments for this trait, with side-dressing (N2) resulting in a substantial plant height increase of 57 cm in sowing date 1 and a smaller increase of 16 cm in sowing date 2 (Table 1.11). Side-dressing treatments and photoperiod treatments had no significant interaction ($P = 0.731$) for plant height, indicating nitrogen fertility and day length exerted independent effects on this trait. The interaction of sowing dates and nitrogen side-dressing treatments was highly significant ($P = 0.002$) for plant height (Table 1.9) as a result of a large increase in the proportion response to side-dressing in the second sowing date, perhaps due to a more severe nitrogen deficiency (due to leaching of the basal fertilizer application) in the second sowing date (data not shown). The interaction between photoperiod, sowing date and nitrogen side-dressing treatments was not significant ($P = 0.919$) for plant height.

Furthermore, there were highly significant differences ($P < 0.001$) between the nine genotypes for plant height. Moreover, the genotypes interacted with photoperiod for this trait, ($P < 0.001$). As indicated in Table 1.10, significance of this interaction was due to the large rank-order changes of genotypes 2 (ICMV 155 TCP), 4 (ICMV 155 *Bmr*) and 8 (ICMV 155 early) in the two day length treatments. Reasons for these rank changes are not clear.

The interaction between sowing dates and genotypes was not significant ($P = 0.159$) for plant height. But the nine genotypes interacted with the two nitrogen side-dressing treatments ($P = 0.003$) for this trait. This implies that nitrogen side-dressing treatments affected plant heights of the different genotypes in different ways. From Table 1.11, it is clear that rank-order changes involving entries 1 (Original ICMV 155 recurrent parent/base population), 7 (ICMV 155 E_1E_1), 2 (ICMV 155 TCP) and 3 (ICMV 155 *bmr*) across the two side-dressing treatments were largely responsible for significance of this interaction. The early genotype ICMV 155 e_Ie_I had consistent rank (lowest) across all four environments.

The interaction between photoperiod, sowing date and genotype treatments, was not significant ($P = 0.283$) for the plant height. In addition, there was no significant ($P = 0.189$) interaction between photoperiod, nitrogen and genotype treatments. However, interaction between sowing date, nitrogen side-dressing, and genotype treatments was significant ($P = 0.014$) for plant height indicating that these three factors contributed to the observed differences in plant height in a non-additive manner.

Comparison of the ICMV 155 e_Ie_I genotype with other eight genotypes for plant height (Table 1.10) using L.S.D. (10.8) was made in each of the two photoperiod regimes.

Under normal day lengths, there was no significant difference for plant height between the ICMV 155 e_Ie_I genotype and any other genotype except ICMV 155 TCP and ICMV 155 E_IE_I. This implied that under normal day length, plant height, the ICMV e_Ie_I genotype was essentially comparable to that of other entries even though it ranked last. However, under the extended day length treatment the ICMV 155 e_Ie_I genotype was significantly shorter than all the genotypes. This was because the height of the ICMV 155 e_Ie_I genotype increased to a smaller extent (29 cm) under extended day lengths than other genotypes (43 to 65 cm). However, in the extended day length treatment, plants of all nine genotypes attained greater height than in the normal day length (Table 1.10).

Furthermore, the ICMV 155 e_Ie_I genotype was compared with other genotypes for plant height (Table 1.11) in each of the four sowing date x nitrogen side-dressing treatment combination using L.S.D. (22.73). In the interaction of sowing date, nitrogen and genotypes, the ICMV 155 e_Ie_I genotype in the SD1, N1 environment showed no significant difference compared with all the other genotypes. This implied that in less fertile soil, the difference in plant height was not significant. On the other hand, the ICMV 155 e_Ie_I genotype in same sowing date of N2 showed significant difference with all the genotypes for plant height except with genotype ICMV 155 early and ICMV 155 *bmr*. This implied that the ICMV 155 e_Ie_I genotype was less responsive to soil fertility improvement than most other genotypes in this study. In SD2, N1 environment the ICMV 155 e_Ie_I genotype had no significant difference for plant height compared with the other genotypes. In the same sowing date of N2, the ICMV 155 e_Ie_I genotype was significantly shorter than all other genotypes studied except ICMV 155 (original).

Table 1.13: Analysis of variance of plant count per ha in Experiment 1.

Source of variation	d.f.	S.S.	%SS	S.S.	v.r.	F pr.
Rep stratum	2	2.117E+09	2%	1.058E+09	14.70	
Rep.Photopd stratum						
Photopd	1	2.192E+09	3%	2.192E+09	30.45	0.031 *
Residual	2	1.440E+08	0%	7.199E+07	0.19	
Rep.Photopd.Sdate stratum						
Sdate	1	4.401E+10	51%	4.401E+10	114.22	<.001 ***

Photopd.Sdate	1	9.043E+09	11%	9.043E+09	23.47	0.008	**
Residual	4	1.541E+09	2%	3.854E+08	2.04		
Rep.Photopd.Sdate.N stratum							
N	1	1.913E+07		1.913E+07	0.10	0.758	NS
Photopd.N	1	8.789E+08		8.789E+08	4.66	0.063	NS
Sdate.N	1	2.894E+08		2.894E+08	1.53	0.251	NS
Photopd.Sdate.N	1	5.367E+08		5.367E+08	2.84	0.130	NS
Residual	8	1.509E+09	2%	1.887E+08	1.55		
Rep.Photopd.sdate.N.Geno stratum							
Geno	8	8.428E+08		1.054E+08	0.86	0.548	NS
Photopd.Geno	8	1.313E+09		1.641E+08	1.35	0.226	NS
Sdate.Geno	8	1.545E+09		1.931E+08	1.58	0.135	NS
N.Geno	8	1.744E+09		2.180E+08	1.79	0.084	NS
Photopd.Sdate.Geno	8	9.452E+08		1.181E+08	0.97	0.463	NS
Photopd.N.Geno	8	1.970E+08		2.462E+07	0.20	0.990	NS
Sdate.N.Geno	8	4.455E+08		5.569E+07	0.46	0.884	NS
Residual	136	1.657E+10	19%	1.219E+08			
Total	215	8.589E+10					

Plant Count

In the analysis of variance of Experiment 1 for number of plants per ha (Table 1.13), photoperiod treatments were significant (P = 0.031), but accounted for only 3% for the observed variation, because of the larger effect of sowing date x photoperiod treatments (see below). In addition, there was a highly significant (P < 0.001) effect of the sowing dates for this character, accounting for over 50% of the observed variation for it in this experiment. This implies that there were differences in plant establishment between the two sowing dates. This likely occurred because of the wet soil conditions at the time of the second sowing. These were especially problematic in the normal day length portion of the experiment, where this second sowing date was machine-sown resulting in soil compaction. To avoid moving the light strings, the second sowing of the extended day length portion of this experiment was sown by hand. These differences in sowing methods are probably responsible for the significant (P = 0.008) sowing date x photoperiod interaction for plant number per ha, as well as the significant photoperiod effect on this trait.

There were no significant effects of nitrogen side-dressing treatments (P = 0.750) or genotypes (P = 0.548), or any of the interactions involving these two groups of treatments, on the observed variation in plant number per ha.

Table 1.14: Analysis of variance of panicle count (numbers of panicles per ha) in Experiment 1.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	1.254E+09	1%	6.270E+08	0.30	
Rep.Photopd stratum						
Photopd	1	2.414E+10	15%	2.414E+10	11.65	0.076 NS
Residual	2	4.144E+09	3%	2.072E+09	2.36	
Rep.Photopd.Sdate stratum						
Sdate	1	3.393E+10	21%	3.393E+10	38.69	0.003 **
Photopd.Sdate	1	7.681E+09	5%	7.681E+09	8.76	0.042 *
Residual	4	3.508E+09	2%	8.769E+08	0.84	
Rep.Photopd.Sdate.N stratum						
N	1	2.065E+10	13%	2.065E+10	19.89	0.002 **
Photopd.N	1	6.469E+08		6.469E+08	0.62	0.453 NS
Sdate.N	1	9.178E+08		9.178E+08	0.88	0.375 NS
Photopd.Sdate.N	1	1.236E+09		1.236E+09	1.19	0.307 NS
Residual	8	8.305E+09	5%	1.038E+09	4.75	
Rep.Photopd.Sdate.N.Geno stratum						
Geno	8	1.507E+10	9%	1.883E+09	8.62	<.001 ***
Photopd.Geno	8	5.864E+09	4%	7.330E+08	3.36	0.002 **
Sdate.Geno	8	1.510E+09		1.887E+08	0.86	0.549 NS
N.Geno	8	1.714E+09		2.143E+08	0.98	0.453 NS
Photopd.Sdate.Geno	8	1.264E+09		1.580E+08	0.72	0.670 NS
Photopd.N.Geno	8	1.202E+09		1.503E+08	0.69	0.701 NS
Sdate.N.Geno	8	7.132E+08		8.915E+07	0.41	0.914 NS
Residual	136	2.970E+10	18%	2.184E+08		
Total	215	1.634E+11				

Table 1.15: Ranked genotypes of number of panicles per ha in the interaction of photoperiod and genotypes (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late, Initial photoperiods: Normal = 13.9 h, Extended = 14.7 h); Patancheru, RCE 24, rainy season 1998.

Rank	Normal	Extended	EDLN – Normal Difference
1	2(129762)	**6(113500)**	2(-41476)
2	5(121428)	8(102381)	3(-30547)
3	**6(121428)**	5(101381)	4(-26000)
4	4(117667)	9(100786)	7(-24214)
5	1(113881)	1(93071)	1(-20810)
6	9(111309)	4(91667)	5(-20042)
7	8(111119)	2(88286)	9(-10523)
8	3(105357)	7(79167)	8(-2738)
9	7(103381)	3(74809)	**6(-7928)**
Mean	115047	93881	

L.S.D. = 20052

Panicle Count

In the analysis of variance of panicle count per ha, photoperiod had no significant effect (P = 0.076) for this character (Table 1.14). This implied that across sowing dates and genotypes, variation in day length did not influence the number of panicles per ha. However, since photoperiod treatments accounted for 15% of the observed variation in this character, and did interact significantly with both sowing dates and genotypes for this character (see below), it none-the-less made an important contribution to observed variation.

When sowing dates were evaluated, there was a highly significant difference (P = 0.003) between the two sowing dates for panicle counts per ha indicating that sowing date had contributed to differences in number of fertile tillers observed across this environment. Moreover, sowing date interacted significantly (P = 0.042) with photoperiod, for number of panicles per ha showing that variation in day length and sowing time contributed in a non-additive manner to the differences in numbers of fertile panicles.

The application of nitrogen side-dressing contributed highly significantly (P = 0.002) to variation in numbers of panicles per ha, which implied that soil fertility differences between treatment that did or did not received a side-dressing of nitrogen influenced the numbers of fertile panicles observed in this experiment.

The interaction of photoperiod and nitrogen was not significant ($P = 0.453$) for numbers of panicles. This indicated that variation in day length and nitrogen rate did not contributed in a non-additive manner to the observed differences in numbers of fertile panicles. Further, the interaction of sowing date and nitrogen was not significant ($P = 0.375$) for this same trait. Thus, the effect of sowing date and nitrogen side-dressing treatments were essentially additive for panicle numbers.

The three-way interaction between photoperiod, sowing date and nitrogen side-dressing treatments was not significant ($P = 0.307$) for numbers of panicles, indicating that variation in these factors had no non-additive influence on the observed differences in numbers of panicles.

In the analysis of variance for panicle number per ha, genotypes showed highly significant differences ($P < 0.001$) for this trait indicating that differences between genotypes had influenced the observed numbers of panicles per ha. Moreover, the genotypes interacted with photoperiod highly significantly ($P = 0.002$) for this trait. This indicated that variation in genotypic responses to day length treatments had contributed to observed variation in the number of panicles per ha. However, interaction of genotypes with sowing date treatments, was not significant ($P = 0.549$) for this character. Similarly, in the interaction of genotypes with nitrogen side-dressing treatments was not significant ($P = 0.453$). This implied that variation in these factors did not contribute in a non-additive manner to observed differences in numbers of panicles per ha.

The three-way interaction between photoperiod, sowing date and genotype treatments was not significant ($P = 0.670$) for numbers of panicles. Similarly, the interaction of photoperiod, nitrogen and genotype treatments was not significant ($P = 0.701$) for this character. Finally, the interaction of sowing date, nitrogen side-dressing and genotype treatments were not significant (P = 0.914) for this character. This implied that interactions of these treatments had no non-additive influences on the observed differences in panicle numbers per ha in this experiment.

As the interaction of photoperiod and genotype treatments was significant, comparison of the ICMV 155 e_1e_1 genotype and the remaining genotypes was made separately under the two photoperiod regimes for panicle counts per ha (Table 1.15) using L.S.D. (20052). Under normal day length, it was observed ICMV 155 e_1e_1 had panicle counts on par with all other genotypes in this study. This implied that the e_1 gene did not positively or negatively influence numbers of fertile panicles under these conditions. However, in the extended day length treatment, the ICMV 155 e_1e_1 genotype showed significantly higher panicle numbers than other genotypes except ICMV 155 early, ICMV155 Bristled and ICMV 155 late. In both photoperiod regimes, ICMV 155 E_1E_1 and ICMV 155 *bmr* had the lowest panicle numbers. Moreover, the across genotypes mean for number of panicles per ha under normal day length was higher than that in the extended day length treatment (115047 to 93881). This is most likely because delayed panicle initiation, especially in the more photoperiod-sensitive genotypes, resulted in maintenance of apical dominance of the main stem growing point for a longer period of time, ultimately reducing the number of productive tillers produced in genotypes that flowered later. The genotypes most sensitive to photoperiod are ICMV 155 TCP and ICMV 155 *bmr* and the least sensitive are ICMV 155 late, ICMV 155 early and ICMV 155 e_1e_1 for the trait panicle number per ha (Table 1.15).

Table 1.16: Analysis of variance of panicle yield (kg ha^{-1}) in Experiment 1.

Source of variation	d.f.	s.s.	%ss	m.s.	v.r.	F pr.
Rep stratum	2	3.109E+06	2%	1.555E+06	1.64	
Rep.Photopd stratum						
Photopd	1	1.602E+06		1.602E+06	1.69	0.323 NS
Residual	2	1.897E+06	1%	9.487E+05	0.64	
Rep.Photopd.Sdate stratum						
Sdate	1	3.021E+07	19%	3.021E+07	20.28	0.011 *
Photopd.Sdate	1	7.909E+04		7.909E+04	0.05	0.829 NS
Residual	4	5.957E+06	4%	1.489E+06	4.00	
Rep.Photopd.Sdate.N stratum						
N	1	7.248E+07	46%	7.248E+07	194.62	<.001 ***
Photopd.N	1	1.079E+05		1.079E+05	0.29	0.605 NS
Sdate.N	1	5.883E+06	4%	5.883E+06	15.80	0.004 **
Photopd.Sdate.N	1	3.382E+05		3.382E+05	0.91	0.368 NS
Residual	8	2.979E+06	2%	3.724E+05	3.16	
Rep.Photopd.Sdate.N.Geno stratum						
Geno	8	8.534E+06	5%	1.067E+06	9.04	<.001 ***
Photopd.Geno	8	1.577E+06		1.972E+05	1.67	0.111 NS
Sdate.Geno	8	1.920E+06	1%	2.400E+05	2.03	0.047 *
N.Geno	8	1.343E+06		1.678E+05	1.42	0.192 NS
Photopd.Sdate.Geno	8	8.256E+05		1.032E+05	0.87	0.540 NS
Photopd.N.Geno	8	8.472E+05		1.059E+05	0.90	0.521 NS
Sdate.N.Geno	8	1.442E+06		1.802E+05	1.53	0.153 NS
Residual	136	1.605E+07	10%	1.180E+05		
Total	215	1.572E+08				

Table 1.17: Ranked genotypes (panicle yield kg ha^{-1}) in the interaction of sowing dates and genotypes (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_le_l, 7 = ICMV 155 E_lE_l, 8 = ICMV 155 early, 9 = ICMV 155 late, Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, RCE 24, Rainy season 1998.

Rank	SD1	SD2	SD2/SD1 x 100%	SD1 – SD2
1	5(2421)	2(1584)	2(75)	1(945)
2	8(2386)	9(1554)	4(73)	8(933)
3	9(2257)	5(1522)	3(70)	7(918)
4	**6(2199)**	8(1453)	9(69)	5(899)
5	1(2141)	4(1412)	5(63)	**6(833)**
6	2(2114)	**6(1366)**	**6(62)**	9(703)
7	7(2012)	1(1196)	8(61)	2(530)
8	4(1927)	7(1094)	1(56)	4(515)
9	3(1540)	3(1083)	7(54)	3(457)
Mean	2111	1363		

L.S.D. = 470

Panicle Yield

In the analysis of variance of panicle yield per ha (Table 1.16) in this experiment, photoperiod did not contribute significantly ($P = 0.323$) to variation.

When the effect of sowing date was evaluated for panicle yield, the difference was significance ($P = 0.011$) between the two sowing dates indicating that time of sowing influenced this character. Sowing date did not interact with photoperiod, as there was no significant ($P = 0.829$) non-additve relationship between the effects of these two factors on panicle yield. Therefore, delayed sowing resulted in a similar reduction in panicle yield, regardless of the photoperiod.

From the analysis of variance, it was observed that there was a highly significant difference ($P < 0.001$) between the two nitrogen side-dressing treatments (+ and -) for panicle yield. This indicated that the panicle yield was influenced to great extent by soil fertility treatment differences. Furthermore, the nitrogen treatments interacted with sowing dates in a highly significant manner ($P = 0.004$) for panicle yield. This implied that variation in sowing date and soil fertility can interact non-additively to influence panicle yields. However, nitrogen side-dressing treatments did not interacted with photoperiod treatments ($P = 0.111$) for panicle yield showing that the differences in day length and soil fertility treatments did not contribute non-additively to panicle yield variation.

The three-way interaction between photoperiod, sowing date and nitrogen side-dressing treatment, was not significant ($P = 0.368$) for panicle yield.

Genotypes were evaluated for their effect on panicle yield. It was observed that there were highly significant differences ($P < 0.001$) between the genotypes for this character. Further, the genotypes interacted significantly with sowing date treatments, for ($P = 0.047$) indicating that some genotypes responded differently than others to the sowing date treatments, at least for this character.

The interaction between photoperiod and genotype treatments was not significant ($P = 0.111$) for panicle yield. Similarly, the interaction of nitrogen side-dressing and genotype treatments was not significant ($P = 0.192$) for this character.

Finally none of the three-way interactions between photoperiod, sowing date and genotype treatments; between photoperiod, nitrogen side-dressing and genotype treatments; and between sowing dates, nitrogen side-dressing and genotype treatments was significant for panicle yield (Table 1.16). This indicates there were no non-additive relationships between any of the three possible groups of three treatments in this experiment.

Since the interaction of sowing dates and genotypes was significant, the ICMV 155 e_1e_1 genotype was compared with the rest of the genotypes within individual sowing dates (Table 1.17) using L.S.D. (470). In sowing date 1 (25 June), it was observed that the ICMV 155 e_1e_1 genotype was not significantly different from any of the remaining genotypes except ICMV 155 *bmr*, which had the lowest mean panicle yield. This implies that in sowing date 1 presence of the e_1 gene in homozygous form did not adversely affect panicle yield. In sowing date 2, panicle yield of the ICMV 155 e_1e_1 genotype was not significantly different from that of any of the remaining eight genotypes. The low yield obtained in this sowing date 2 could be due to crusting and soil compaction problems at the time of crop emergence. The mean panicle yield per ha in sowing date 1 was higher than sowing date 2 (2111 to 1363).

For this character, the genotypes to sowing date most sensitive are ICMV 155 (original), ICMV 155 early and ICMV 155 E_1E_1, while the least sensitive are ICMV 155 TCP, ICMV 155 *Bmr* and ICMV 155 *bmr* (Table 1.17).

4.2. Results of Experiment 2

The bird damage experiment was conducted in two sites. The first site was not protected from birds and the soil was relatively fertile. The second site was fully protected from birds using two bird scarers for the whole day (from 6:00 am. until 7:00 pm. in the evening, for the entire period during which any entry x treatment combination in the trial was in the bird-vulnerable grain filling period). But this was also confounded with the inherent soil fertility of two sites. The soil fertility status at this second site was lower than the first one.

The main objective of the second experiment was to determine the effect of the long panicle bristling character on grain vulnerability to bird damage. The bird scaring treatments (+ and -) were assigned to the main plots, sowing dates to the sub-plots and the nine genotypes to the sub-sub-plots. Analyses of variance for this experiment are shown as follows in Table 2.1, 2.3, 2.5, 2.7, 2.9, 2.11 and 2.13, accompanied by L.S.D. comparisons of genotypes when the ANOVA indicates significant genotype differences.

Table 2.1: Analysis of variance of grain yield (kg ha^{-1}) in Experiment 2.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.	
Rep stratum	2	1.678E+06	1.6%	8.390E+05	17.52		
Rep.Scare stratum							
Scare	1	5.937E+06	5.7%	5.937E+06	123.99	0.008	**
Residual	2	9.576E+04	0.1%	4.788E+04	0.07		
Rep.Scare.Sdate stratum							
Sdate	1	9.267E+06	8.9%	9.267E+06	14.16	0.020	*
Scare.Sdate	1	6.230E+07	59.6%	6.230E+07	95.20	<.001	***
Residual	4	2.618E+06	2.5%	6.544E+05	4.49		
Rep.Scare.Sdate.Gtype stratum							
Gtype	8	4.144E+06	4.0%	5.180E+05	3.55	0.002	**
Scare.Gtype	8	2.218E+06		2.772E+05	1.90	0.075	NS
Sdate.Gtype	8	1.907E+06		2.384E+05	1.64	0.132	NS
Scare.Sdate.Gtype	8	4.961E+06	4.7%	6.202E+05	4.25	<.001	***
Residual	64	9.330E+06	8.9%	1.458E+05			
Total	107	1.045E+08					

Table 2.2: Ranked genotypes of mean grain yield (kg ha^{-1}) with (field RCE 24) and without (field RP 2A) bird scaring in two sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; SD1 = sowing date 1: 25 June, SD2 = sowing date 2: 9 July); Patancheru, RCE 24 and RP 2A, Normal Day Length Nurseries, rainy season 1998.

	Without Bird scarers		With Bird scarers	
RANK	SD1	SD2	SD1	SD2
1	7(1662)	7(3855)	**5(2574)**	2(1819)
2	**5(1650)**	8(3652)	7(2321)	**5(1398)**
3	3(1493)	1(3548)	9(2293)	4(1331)
4	4(1098)	9(3529)	8(2263)	8(1243)
5	1(1018)	**5(3205)**	6(2252)	3(1143)
6	9(879)	2(3031)	2(2174)	7(1107)
7	2(867)	4(3005)	1(2091)	9(1091)
8	8(779)	6(3000)	4(1976)	1(1024)
9	6(614)	3(2174)	3(1564)	6(952)
Mean	1117	3222	2167	1234

BS treat means -- 2170 1701

SD means 1.64 t 2.23 t

L.S.D. = 311

Grain Yield

The interaction between the presence/absence of bird scarers and the two sowing dates was highly significant ($P < 0.001$) for grain yield, and accounted for 60% of the total sum of squares for this character (Table 2.1), indicating that optimum sowing date was affected by presence or absence of bird scarers. With bird scarers in sowing date 1 grain yields were higher whereas without bird scarers yields were higher in sowing date 2. This was because feeding by birds was concentrated on this trial in the 1st sowing date but was dispersed to other areas in the 2nd sowing date. Thus it is necessary to separately examine genotype vulnerability to bird damage in the first sowing date as other food sources became available to the birds later in the growing season resulting in less bird pressure for the second sowing date.

The relationship between flowering date and grain yield, both with bird scarers and without bird scarers, was considered. It looks like in the 1st sowing date, grain yield of early flowering entries (ICMV 155 $e_l e_l$ and ICMV 155 early, see Table 2.5 below) was very much reduced in the field without bird scarers compared to that in the field with bird scarers. Bird pressure on the 1st sowing date was greater, and greatest on early-flowering entries in this sowing date. Late-flowering entries in this sowing suffered less bird damage.

This can be demonstrated by regressing grain yield in the plot with and without bird scarers (Y) on genotype flowering time (X). Deviation of observed values (y) from the regression line for the first sowing date x no bird scaring treatment combination (filled diamonds) should be indicative of the inherent bird susceptibility of the genotype adjusted for flowering time (Fig. 4).

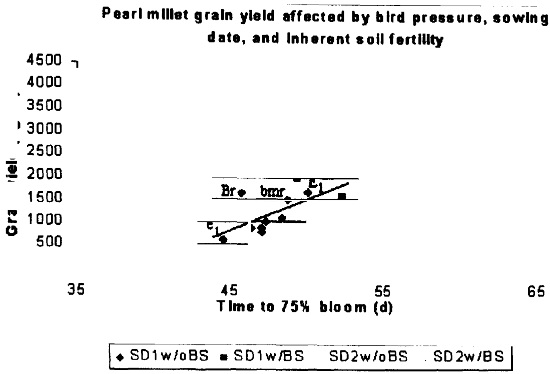

Fig. 4. Regression of grain yield (Y) on flowering date (X) for nine near-isogenic pearl millet varieties sown in two sowing dates in two fields differing in inherent soil fertility and presence/absence of bird scarers.

The analysis of variance of grain yield (Table 2.1), showed highly significant differences (P = 0.008) for grain yield between the fields with and without bird scarers. This is because trial mean yield was highest in the field where there was no bird scarer due to the higher soil fertility at that site. The grand mean from the field without bird scares was 2.17 t ha^{-1} and that from the field with bird scarers was 1.70 t ha^{-1}. This was not the expected effect of the bird scaring treatments, but can reasonably be ascribed to the inherent soil fertility difference between the two fields that was confounded with these two bird scaring treatments.

Similarly, there was significant difference (P = 0.02) between the two sowing dates for grain yield indicating that the sowing dates influenced the grain yields. The mean of sowing date 1 in the two fields was 1.64 t ha^{-1} and sowing date 2 of in both fields was 2.23 t ha^{-1} which was not entirely as expected. The reason for this result was the highly significant interaction between the sowing date and bird scaring treatments (see above). Since this interaction was significant, we should use the bird scarer x sowing date MS (mean square) in the denominator of the v.r. (variance ratio). This then gives a value of 0.15 for sowing date which is not significant, so there was no effect of sowing date on grain yields independent of bird scaring treatments in this experiment. It is possible to estimate the grain the yield of the first sowing date in the field with higher soil fertility had there been bird scarers present, assuming no sowing date x soil fertility interaction and assuming that there was no bird damage in the second sowing date in this field, as follows:

X = (Mean grain yield in SD2 without BS) x (Mean grain yield in SD1 with BS)/(Mean grain yield in SD2 with BS)

= 3222 x (2167/1234)

= 5658 kg ha^{-1}

Thus grain yield loss due to birds in the first sowing date of the field without bird scarers are estimated at 80% across genotypes.

The genotypes showed highly significant variation (P = 0.002) for grain yield indicating that they are different; however, since the bird scarer x sowing date x genotype treatments interaction was significant (P < 0.001), using that MS (mean square) in the denominator of the v.r. (variance ratio) gives a value of 0.835 for genotypes, which is not significant.

There was no significant interaction (P = 0.075) between the presence and absence of bird scarers and genotype indicating that averaged across sowing dates all varieties behaved the same against birds. Similarly, there was no significant interaction (P = 0.132) between the sowing date and genotypes showing that averaged across bird scaring (confounded with soil fertility) treatments had similar grain yield responses to sowing dates. But these non-significant interactions were due to the highly significant bird scarer x sowing date x genotype interaction (P < 0.001).

This interaction of bird scarer x sowing date x genotype treatments was highly significant ($P < 0.001$) for grain yield, resulting in different rankings of genotypes in the four sowing date x bird scarer treatment combinations. Therefore, it is necessary to look in detail at genotype grain yield performance in each of these four environments.

Comparison for yield among the nine genotypes using L.S.D. (311) was made (Table 2.2). In the plots without bird scarers, in the first sowing date, it was observed that grain yield of the ICMV 155 Bristled genotype did not differ significantly from late-flowering ICMV 155 E_lE_l and bending ICMV 155 *bmr* but was significantly greater than the grain yield of all of the rest of the genotypes (see Fig. 4). This is an indication that the bristled genotype was more resistant to the heavy bird pressure in this environment as it was one of the three highest yielding varieties in these conditions and had higher than expected grain yield for its sowing date 1 (Fig. 4). The high yields of ICMV 155 E_lE_l and ICMV 155 *bmr* can safely be attributed to their escape from higher levels of bird feeding due to their later flowering times compared with other genotypes in this environment (Fig. 4).

In sowing date 2 of the same field, the ICMV 155 bristled type yielded significantly less grain than genotypes ICMV 155 E_lE_l, ICMV 155 early, ICMV 155, ICMV 155 late but more than ICMV 155 *bmr*. This indicates that the bristled genotype was lower yielding in this sowing date x soil fertility environment, perhaps due to a lower yield potential under high soil fertility conditions compared with the later-flowering genotypes. Of course, these four later-flowering genotypes were probably also subjected to less feeding by birds than the relatively early-flowering ICMV 155 Bristled genotype.

In the plots with bird scarers, in sowing date 1 there was no significant difference between genotypes ICMV 155 Bristled, ICMV 155 E_lE_l and ICMV 155 late but there was significant difference between ICMV 155 Bristled genotype and the remaining genotypes showing that this genotype had good yield potential due to when protected from birds on less fertile soil. Furthermore, in the same field of sowing date two, the

ICMV 155 Bristled genotype showed significantly higher grain yields than ICMV 155 and ICMV e_le_l but on par with the rest of the genotypes in this trial. ICMV 155 TCP showed significantly higher grain yield than all the other genotypes. Even though the mean yields were low as a result of soil crusting and compaction at the time of seedling emergence in this environment, this entry produced better yields than the other genotypes except ICMV 155 TCP.

Table 2.3: Analysis of variance of total dry matter production (t ha^{-1}) in Experiment 2.

Source of variation	d.f.		%SS	M.S.	v.r.	F pr.
Rep stratum	2	10.6802		5.3401	3.97	
Rep.Scare stratum						
Scare	1	482.5249	62.6%	482.5249	358.49	0.003
Residual	2	2.6920	0.3%	1.3460	0.58	
Rep.Scare.Sdate stratum						
Sdate	1	89.4886	11.6%	89.4886	38.74	0.003
Scare.Sdate	1	65.7015	8.5%	65.7015	28.45	0.006
Residual	4	9.2388	1.2%	2.3097	3.39	
Rep.Scare.Sdate.Gtype stratum						
Gtype	8	30.9495	4.0%	3.8687	5.69	<.001 **
Scare.Gtype	8	14.3469	1.9%	1.7934	2.64	0.015 *
Sdate.Gtype	8	7.3856	1.0%	0.9232	1.36	0.233 NS
Scare.Sdate.Gtype	8	13.7042	1.8%	1.7130	2.52	0.019 *
Residual	64	43.5436	5.7%	0.6804		
Total	107	770.2556				

Table 2.4: Ranked genotypes of total dry matter yield (t ha^{-1}) of the nine near-isogenic pearl millet genotypes with bird scaring and without bird scaring in two sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_le_l, 7 = ICMV 155 E_lE_l, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing date: SD1 = 25 June, SD2 = 9 July); Patancheru, RCE 24 and RP 2A, Normal Day Length Nurseries, rainy season 1998.

	Bird scarers absent (RCE 24)		**Birdscarers present (RP2A)**	
Rank	**SD1**	**SD2**	**SD1**	**SD2**
1	7(10.74)	7(11.30)	7(8.16)	2(4.86)
2	9(10.30)	1(10.31)	**5(7.53)**	4(3.88)
3	**5(9.80)**	8(9.74)	2(7.18)	**5(3.73)**
4	4(9.76)	4(9.55)	8(6.96)	3(3.62)
5	1(9.47)	2(9.36)	9(6.87)	7(3.54)
6	3(9.38)	9(9.32)	4(6.78)	8(3.50)
7	8(9.01)	**5(8.41)**	1(6.55)	9(3.02)
8	6(8.84)	6(8.38)	6(6.24)	6(2.76)
9	2(8.72)	3(7.29)	3(5.73)	1(2.69)
Mean	8.50	9.31	6.88	3.5

BS treat means – 8.90 5.19

SD means 7.69 t 6.41 t

L.S.D. = 0.673

Total Dry Matter Yield

In the analysis of variance for total dry matter yields (Table 2.3), it was observed that the interaction of bird scarer x sow date x genotype treatments was significant (P = 0.019) showing that the sites and sowing dates had genotype-specific effects on the production of total biomass. This again indicates that comparisons among genotypes should be made only within the context of a given site (soil fertility confounded with presence/absence of bird scarers) and sowing date combination.

The interaction between the bird scares and genotypes was significant (P = 0.015) for the total dry matter production indicating that the ranking of genotypes was different in the two fields (with and without bird scarers). The interaction of sowing dates and the genotypes was not significant (P = 0.233) for total dry matter production showing that the variation in genotype ranking was not affected by sowing date. In addition, there was highly significant variation (P < 0.001) between the genotypes indicating that there was difference for growth and tillering ability between them. This variation between genotypes for total biomass yield remained significant even when the MS for the three-way interaction was used as denominator in the variance ratio.

There was a highly significant difference (P = 0.003) between the sites with and without bird scarers. The mean total biomass yield of the unprotected field was observed to be 8.90 t ha^{-1} and in the protected field was 5.19 t ha^{-1} indicating there was growth variation between the two fields. This treatment difference accounted for over 60% of the observed variation for total biomass yield in this experiment and most likely was due to inherent soil fertility differences between these two sites.

Moreover, there was highly significant total biomass yield difference (P = 0.003) between the two sowing dates, accounting for 12% of the observed variation in this trait in Experiment 2, indicating that there was a large effect of the two sowing dates on biomass production. The mean biomass yield across genotypes and bird scaring treatments for sowing date 1 was 7.69 t ha^{-1} and for sowing date 2 was 6.41 t ha^{-1}. Thus sowing date 1 had a better yield than sowing date 2. This result conforms to expectations that timely sowing can give higher biomass yields. However, when using the significant bird scarer x sowing date treatment interaction MS as the denominator of the variance ratio to test significance of sowing date treatments, the sowing date effect was found to be non-significant.

The interaction of bird scarers (confounded sites with different inherent soil fertility) and sowing dates was highly significant (P = 0.006) for total dry matter production as in the case of grain yield, indicating that this interaction influenced both the vegetative and reproductive growth of the plants. In the case of total dry matter yield, this interaction accounted for 9% of the observed variation a level comparable to that of the sowing date treatment themselves. Thus, there was a different biomass yield response to sowing date in the two fields having different bird scaring treatments. This difference in response (late sowing increasing biomass fields in the field without bird scarers, but decreasing yields in the field with bird scarers (Table 2.4)) is probably due to the direct effect of bird pressure in the first sowing date of the unprotected field.

Comparison of genotypes for total dry matter using L.S.D. (0.673) was made in each of the four sowing date x bird scaring treatments (Table 2.4). In the unprotected field, sowing date 1, the ICMV 155 Bristled genotype produced significantly less total dry matter than late-flowering genotype ICMV 155 E_1E_1, but was on par with ICMV 155 late, which ranked second under these conditions. The ICMV 155 Bristled genotype was also on par with genotypes ICMV 155 *Bmr*, ICMV 155 (original) and ICMV 155 *bmr* in terms of total dry matter production. Further, it produced significantly more total dry matter in this environment than entries ICMV 155 early, ICMV 155 e_1e_1 and ICMV 155 TCP.

In the unprotected field, sowing date 2, the ICMV 155 Bristled genotype produced significantly less total dry matter than all the genotypes except with ICMV 155 e_1e_1 (with which it was on par) and ICMV 155 *bmr* (which produced significantly less dry matter than all eight other genotypes in these conditions) indicating that the yield of total dry matter for this genotype was comparatively low. This may have been due to its relatively early flowering time (see Table 2.6).

In the field protected by bird scarers, sowing date 1, the ICMV 155 Bristled genotype was on par with ICMV 155 E_1E_1, ICMV 155 TCP, ICMV 155 early and ICMV 155 late for total dry matter production, and produced significantly more total dry matter than the remaining four genotypes studied. This indicated that the bristled genotype had reasonably high total dry matter yield as compared all other genotypes under these conditions.

Moreover, in comparison of the ICMV 155 Bristled genotype with other genotypes in the bird scarer protected field, sowing date 2, it was observed that there was no significant difference in total dry matter production of this entry with ICMV *Bmr*, ICMV 155 *bmr*, ICMV 155 E_1E_1 and ICMV 155 early. However, the Bristled genotype produced significantly less total dry matter than ICMV 155 TCP, which was the highest yielding under these conditions, and significantly more total dry matter production than the original ICMV 155, ICMV 155 e_1e_1, and ICMV 155 late.

Thus the ICMV 155 Bristled genotype was relatively productive in terms of total dry matter yield in both fields in the first sowing date, but inconsistent in its performance across fields for this trait in the second sowing date.

Table 2.5: Analysis of variance for time to 75% flowering (days) in Experiment 2.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	128.667	3.8%	64.333	1.59	
Rep.Scarer stratum						
Scarer	1	1064.083	31.7%	1064.083	26.31	0.036 *
Residual	2	80.889	2.4%	40.444	1.71	
Rep.Scarer.Sdate stratum						
Sdate	1	366.676	10.9%	366.676	15.54	0.017 *
Scarer.Sdate	1	741.565	22.1%	741.565	31.43	0.005 **
Residual	4	94.370	2.8%	23.593	6.41	
Rep.Scarer.Sdate.Gtype stratum						
Gtype	8	527.000	15.7%	65.875	17.91	<.001 ***
Scarer.Gtype	8	64.667	1.9%	8.083	2.20	0.039 *
Sdate.Gtype	8	20.074	0.6%	2.509	0.68	0.705 NS
Scarer.Sdate.Gtype	8	32.852	1.0%	4.106	1.12	0.364 NS
Residual	64	235.407	7.0%	3.678		
Total	107	3356.250				

Table 2.6: Ranked genotypes of time to 75% flowering (days) of the nine near isogenic-genotypes of ICMV 155 with and without bird scaring within and across two sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, rainy season 1998.

	Without Scarers	**Bird**		**With Bird Scarers**		**(Over Means)**	
Rank	**SD1**	**SD2**	**Mean w/o BS**	**SD1**	**SD2**	**Mean w/ BS**	**Mean across Bs + SD**
1	6(44.47)	6(42.67)	6(43.57)	6(41.67)	**5(52.33)**	6(47.84)	6(45.71)
2	**5(45.67)**	2(44.67)	**5(45.50)**	**5(46.00)**	6(54.00)	**5(49.17)**	**5(47.33)**
3	9(46.33)	8(45.00)	2(45.84)	8(47.33)	2(54.67)	2(51.17)	2(48.50)
4	8(47.00)	**5(45.33)**	9(46.00)	9(47.33)	9(57.00)	9(52.17)	9(49.08)
5	2(47.00)	4(45.67)	8(46.00)	2(47.67)	8(57.33)	8(52.33)	8(49.17)
6	1(47.33)	1(45.67)	1(46.50)	1(49.00)	4(58.33)	4(53.84)	4(50.41)
7	4(48.33)	9(45.67)	4(47.00)	4(49.33)	1(59.67)	1(54.33)	1(50.41)
8	3(48.67)	3(48.00)	3(48.33)	3(52.33)	3(60.00)	3(56.17)	3(52.25)
9	7(50.00)	7(48.33)	7(49.17)	7(53.67)	7(61.33)	7(57.50)	7(53.33
Mean	47.20	45.67	46.44	48.26	57.18	52.72	

BS treat mean – 46.44 52.72 49.58

SD means 47.7 d 51.4 d

L.S.D. = 1.564

Time to 75% Flowering

In the analysis of variance for time to 75% flowering (Table 2.5), it was observed that there was significance differences ($P = 0.036$) between the sites with and without bird scarers. Since bird scarers were not introduced until after the first entries had completed 75% flowering in the first sowing date, the responses observed are most likely due to inherent soil fertility differences between the two fields, and not due to the presence or absence of bird scarers, per se. Across the nine genotypes, the mean for time to 75% flowering in the unprotected field was 46.4 days and 52.7 days in the protected field, indicating that there was a pronounced tendency towards late flowering as the soil fertility decreased. This suggests that under the favorable rainfall condition in which this study was conducted, improving soil fertility can stimulate more rapid growth, resulting in earlier crop flowering and maturity. There was also a significant difference ($P = 0.017$) between the two sowing dates for time to 75% flowering. The mean of time to 75% flowering for sowing date 1 was 47.7 days and for sowing date 2 was 51.4 days, clearly showing that in sowing date 1 plants matured in less time than sowing date 2. However, the interaction of bird scarer and sowing date treatments was highly significant (P = 0.005) for time to 75% flowering, indicating that soil fertility and sowing date effects on flowering were not additive.

Under the higher soil fertility conditions of the field without bird scarers, the shorter day lengths of sowing date 2 resulted in reduced mean time to 75% flowering compared to sowing date 1. Nevertheless, the opposite effect was observed in the lower soil fertility conditions of the bird-protected field, where flowering in second sowing date was delayed compared to the first sowing date. Furthermore, there were highly significant differences (P < 0.001) between genotypes for time to 75% flowering, showing that genetic variation between entries had a substantial influence on time to 75% flowering. Significance of genotypic differences in flowering time held up even when the MS for the significant bird scarer x genotype interaction (see below) was used as denominator of the variance ratio.

The interactions of the bird scarer (confounded with inherent soil fertility of the two sites) and genotype treatments were significant (P = 0.039) for time to 75% flowering indicating that site variation had an influence on the ranking of genotypes for this character. However, the interactions of sowing date x genotype treatments (P = 0.705) and of bird scarers x sowing date x genotype treatments (P = 0.364) were not significant indicating that sowing dates had no influence on the ranking of genotypes for time to 75% flowering.

Comparisons of genotype means for time to 75% flowering were within and across bird scaring treatments done using L.S.D. (1.564) (Table 2.6). The ICMV 155 Bristled genotype was compared for mean time to 75% flowering (across sowing dates and bird scaring treatments), with all remaining genotypes in this study. In general the ICMV 155 Bristled genotype can be categorised as one of the earliest to flower in all the sowing dates and fields. Thus its relatively high grain yield in sowing date 1 of the unprotected field (Table 2.2 and Fig. 4) is a clear indication that panicle bristling does protect grain from damage by birds even in conditions where the birds have only limited quantities of other food sources of similar maturity available.

Table 2.7: Analysis of variance for plant height (cm) in Experiment 2.

Source of variation	d.f.	s.s.				F pr.
Rep stratum	2	642.1	0.3%	321.1	0.48	
Rep.Scarer stratum						
Scarer	1	108046.8	52.8%	108046.8	161.70	0.006 **
Residual	2	1336.4		668.2	3.83	
Rep.Scarer.Sdate stratum						
Sdate	1	59925.3	29.3%	59925.3	343.65	<.001 ***
Scarer.Sdate	1	14793.5	7.2%	14793.5	84.83	<.001 ***
Residual	4	697.5		174.4	1.40	
Rep.Scarer.Sdate.Gtype stratum						
Gtype	8	5254.3	2.6%	656.8	5.28	<.001 ***
Scarer.Gtype	8	2494.9		311.9	2.51	0.020 *
Sdate.Gtype	8	2109.7		263.7	2.12	0.047 *
Scarer.Sdate.Gtype	8	1209.9		151.2	1.22	0.305 NS
Residual	64	7963.3		124.4		
Total	107	204473.6				

Table 2.8: Ranked genotypes of mean plant height of the nine near-isogenic pearl millet genotypes with and without bird scaring in two sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, rainy season 1998.

	Without Bird Scarers			With Bird Scarer					
Rank	**SD1**	**SD2**	**Mean w/o BS**	**SD1**	**SD2**	**Mean w/ BS**	**Mean SD1**	**Mean SD2**	**Mean**
1	7(279)	1(251)	7(265)	7(244)	2(164)	2(196)	7(262)	9(204)	7(231)
2	1(277)	7(251)	1(264)	4(229)	**5(159)**	7(195)	1(250)	2(202)	9(225)
3	4(270)	9(249)	4(258)	2(228)	9(159)	9(193)	4(249)	8(198)	2(223)
4	8(267)	4(246)	9(257)	9(228)	8(158)	**5(192)**	9(247)	7(198)	4(223)
5	9(265)	2(240)	8(253)	**5(225)**	3(155)	4(188)	**5(245)**	4(197)	1(223)
6	**5(264)**	8(239)	2(250)	1(223)	6(152)	8(188)	2(244)	1(196)	8(220)
7	2(260)	**5(231)**	**5(248)**	8(217)	4(147)	3(186)	8(242)	**5(195)**	**5(220)**
8	3(255)	6(227)	3(240)	3(216)	7(145)	1(182)	3(235)	3(190)	3(213)
9	6(235)	3(225)	6(231)	6(205)	1(140)	6(179)	6(220)	6(189)	6(205)
Mean	264	240		224	153		244	197	220
BS treat means			252			189			
SD means			244 cm			197 cm			

L.S.D. = 9.10

Mean Plant Height

From the analysis of variance of plant height (Table 2.7), it was observed that there was a highly significant difference ($P = 0.006$) in plant height between the sites with and without bird scarers. Like the effect of these two sites on flowering time, this is indicative of the relative soil fertility of the two sites rather than of any direct effect of the presence or absence of bird scarers per se. The mean plant height in the unprotected field was 252 cm and in the protected field was 189 cm, indicating there was better growth in the unprotected field due to the inherent fertility difference between the two sites.

There was a highly significant ($P < 0.001$) difference between the two sowing dates. The mean of sowing date 1 was observed to be 244 cm and sowing date 2 was 197 cm indicating that sowing date 1 had better growth conditions than sowing date 2. The factors probably responsible for this differences are: 1) the longer day lengths of sowing date 1 at the end of juvenile growth phase delayed flowering thereby contributing to increased plant height; and 2) there was some leaching of basal fertilizer before the second sowing was made.

The interaction of bird scarer and sowing date treatments on plant height was highly significant ($P < 0.001$) showing that the variation in soil fertility combined together with the sowing dates had influenced the plant height in a non-additive manner. Essentially, the reduction in plant heights for sowing date 2 was greater in the field having lower inherent soil fertility. Another factor contributing to this poor performance in the second sowing date in this field was that there was serious problem with soil compaction there in the second sowing date.

Moreover, there were highly significant differences ($P < 0.001$) between genotypes for plant height indicating that genotypic variation between the near-isogenic versions of ICMV 155 was important for this trait. There was a significant ($P = 0.02$) interaction of bird scarer and genotype treatments for plant height indicating that variation between fields acted non-additively with genotypes in determining plant heights. The interaction of sowing date and genotype treatments was also significant ($P = 0.047$) for plant height implying that the variation in sowing dates and genotypes could combine to affect plant height in non-additive manner.

No significant interaction of bird scarer x sowing date x genotype treatments, ($P = 0.305$) was observed for plant height in this experiment indicating that this type of interaction did not have influence on growth of the plants. Using the MS for this non-significant 3-way interaction as the error term resulted in the bird scarer x genotype and sowing date x genotype interactions being non-significant for this trait. Hence, comparison of genotype means for plant height across the four sowing date x site environments is appropriate. Only ICMV 155 e_1e_1 and ICMV 155 *bmr* were significantly shorter than ICMV 155 Bristled genotype (Table 2.8). Except for ICMV 155 *bmr*, the later-flowering group (ICMV 155 E_1E_1, ICMV 155 late, ICMV 155 TCP, ICMV 155 *Bmr*, ICMV 155 original and ICMV 155 early) tended to be slightly taller than the earlier-flowering group (ICMV 155 Bristled, ICMV 155 TCP, and ICMV 155 e_1e_1)

The ICMV 155 Bristled genotype had medium height (mean of 220 cm, essentially same as the trial grand mean) so it is not likely that it escaped from birds due to short plant height (birds prefer to feed on tall plants so as to keep a watch on potential predators ...). However, when ICMV 155 Bristled genotype was compared in the field with no bird scarers, sowing date 2, with other genotypes sown in these conditions, it was significantly shorter than ICMV 155 (original), ICMV 155 E_1E_1, ICMV 155 late, ICMV 155 *Bmr* and ICMV 155 TCP indicating that some varieties were significantly taller than ICMV 155 Bristled in this environment despite its having attained medium height there.

In the field with bird scarers, sowing date 1, the ICMV 155 Bristled genotype was significantly shorter than only ICMV 155 E_1E_1, and significantly taller than only ICMV 155 *bmr* and ICMV 155 e_1e_1; being on par for plant height with the remaining five genotypes. In addition, the ICMV 155 Bristled genotype in the field with bird scarers, sowing date 2, was significantly taller than ICMV 155 *Bmr*, ICMV 155 E_1E_1 and ICMV 155 (original), indicating that this genotype attained plant height as good as or better than all the genotypes despite the soil compaction problem in this environment that reduced heights of all genotypes to less than normal compared to the other three environments.

Table 2.9: Analysis of variance of plant population (plant count ha^{-1}) in Experiment 2.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	5.298E+08	1.9%	2.649E+08	0.24	
Rep.Scarer stratum						
Scarer	1	1.312E+06	0.0%	1.312E+06	0.00	0.976 NS
Residual	2	2.228E+09	7.9%	1.114E+09	3.02	
Rep.Scarer.Sdate stratum						
Sdate	1	3.276E+08	1.2%	3.276E+08	0.89	0.399 NS
Scare.Sdate	1	8.356E+09	29.7%	8.356E+09	22.64	0.009 **
Residual	4	1.476E+09	5.2%	3.691E+08	2.20	
Rep.Scarer.Sdate.Gtype stratum						
Gtype	8	1.028E+09	3.6%	1.285E+08	0.77	0.632 NS
Scare.Gtype	8	6.416E+08	2.3%	8.020E+07	0.48	0.867 NS
Sdate.Gtype	8	1.897E+09	6.7%	2.371E+08	1.42	0.207 NS
Scare.Sdate.Gtype	8	9.316E+08	3.3%	1.164E+08	0.70	0.694 NS
Residual	64	1.072E+10	38.1%	1.675E+08		
Total	107	2.814E+10				

Table 2.10: Ranked genotypes of plant population (plants per ha) of the nine near-isogenic pearl millet genotypes with bird scaring and without bird scaring in two sowing dates (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, rainy season 1998.

	Without Bird Scarers		With bird Scarers	
Rank	SD1	SD2	SD1	SD2
1	8(119048)	6(136428)	6(133333)	2(121428)
2	7(113571)	7(133333)	**5(130952)**	6(113571)
3	**5(111905)**	1(126905)	9(128571)	4(111190)
4	2(110238)	2(125476)	1(128571)	7(108809)
5	9(107857)	4(123095)	4(127857)	3(107143)
6	1(107143)	9(119762)	8(126905)	1(100000)
7	3(106428)	**5(118333)**	3(123809)	**5(100000)**
8	4(104762)	8(115000)	2(123095)	8(98333)
9	6(100714)	3(110238)	7(119047)	9(96905)
Mean	109071	123190	126905	106357

BS treat means 116131 116631

SD means 117988 plants 114774

L.S.D. = 10555

Plant Population

In the analysis of variance of plants per ha (Table 2.9), there was no significant difference ($P = 0.976$) between the sites with and without bird scarers for the number of plants per unit area. The mean of the unprotected field was 116131 and the protected field had 116631 plants ha^{-1} indicating that on average genotypes established in a similar manner in the two sites.

The two sowing dates did not differ significantly ($P = 0.399$) for mean plant population. The mean of sowing date 1 was observed to be 117988 plants ha^{-1} and sowing date 2 was 114774 plants ha^{-1} indicating that sowing date independent of other treatments, had no influence on the crop establishment.

However, the interaction of bird scarer treatments (confounded with sites) and sowing dates was highly significant ($P = 0.009$) for plant numbers, indicating that the variation in the plant population did not respond to sowing date in the same manner in the two fields. There were stand establishment difficulties in the first sowing date in the field without bird scarers (especially for genotype ICMV 155 e_1e_1) due to post-sowing pre-emergence soil surface crusting and in the second sowing date in the field with bird scarers due to soil compaction.

There was no significant variation ($P = 0.632$) between genotypes for plant population showing that crop establishment was not influenced by variation between the nine genotypes.

The interaction of bird scarer treatments and genotypes was not significant ($P = 0.867$) for plant population indicating that the interaction between in sites and genotypes had no consistent effect on crop establishment. Similarly, the interaction between the sowing dates and genotypes had no significant variation ($P = 0.207$) for plant population showing interaction between sowing dates and genotypes had no consistent effects on the plant numbers per ha. The interaction between bird scarer, sowing date, and genotype treatments was also not significant ($P = 0.694$).

As the effect of genotype, and all possible treatment interactions involving genotype, on plant population were not significant in this experiment, it was not necessary to compare genotype means within across the four sowing date x bird scarer treatment environments.

Table 2.11: Analysis of variance of plant panicle count (number of panicles per ha) in Experiment 2.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	2.698E+09	2.8%	1.349E+09	4.12	
Rep.Scarer stratum						
Scarer	1	3.193E+10	33.0%	3.193E+10	97.64	0.010 *
Residual	2	6.541E+08	0.7%	3.271E+08	0.38	
Rep.Scarer.Sdate stratum						
Sdate	1	7.813E+08	0.8%	7.813E+08	0.92	0.392 NS
Scarer.sdate	1	7.500E+09	7.7%	7.500E+09	8.83	0.041 *
Residual	4	3.399E+09	3.5%	8.497E+08	1.91	
Rep.Scarer.Sdate.Gtype stratum						
Gtype	8	8.049E+09	8.3%	1.006E+09	2.26	0.034 *
Scarer.Gtype	8	6.627E+09	6.8%	8.284E+08	1.86	0.082 NS
Sdate.Gtype	8	3.625E+09	3.7%	4.532E+08	1.02	0.432 NS
Scarer.Sdate.Gtype	8	3.103E+09	3.2%	3.878E+08	0.87	0.546 NS
Residual	64	2.852E+10	29.4%	4.456E+08		
Total	107	9.689E+10				

Table 2.12: Ranked genotypes of number of panicles per ha of nine near-isogenic pearl millet genotypes in two sowing dates at sites with bird scaring and without bird scaring (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, rainy season 1998.

	Without Bird Scarers		With bird Scarers		Mean across sites & sowing dates
Rank	SD1	SD2	SD1	SD2	
1	6(207143)	1(180952)	2(157143)	2(139690)	6(164286)
2	9(170643)	6(180166)	6(148405)	4(125405)	2(149762)
3	1(161905)	8(175405)	**5(142071)**	6(121428)	1(145238)
4	**5(157143)**	2(168262)	9(138095)	**5(116667)**	9(144047)
5	3(146833)	3(164286)	8(132547)	3(114286)	**5(143571)**
6	4(146024)	9(161119)	7(130952)	1(107928)	3(138571)
7	7(144452)	7(159523)	1(130167)	9(106357)	4(138095)
8	2(134119)	**5(157928)**	3(129357)	7(105548)	7(135238)
9	8(129357)	4(151595)	4(129357)	8(102381)	8(135000)
Mean	155238	166667	137619	115476	

BS treat means 160953 126548

SD means 146429 panicles 141072 panicles

L.S.D. = 17214

Panicle Count

In the analysis of variance of number of panicles per ha (Table 2.11), there were highly significant differences (P = 0.010) between the sites with and without bird scaring. The mean panicle number in the unprotected site was 160953 panicles ha^{-1} and in the protected site was 126548 panicles ha^{-1} indicating that site variation had an influence on the number of productive tillers. Part of this could have been a direct result of bird damage destroying sinks on early maturing panicles, which in turn stimulated production of additional sinks (tillers) by the affected plants. However, part of this difference may also have been due to the inherent soil fertility differences between the two sites, with larger number of tillers being produced in the field with higher soil fertility.

There was no significant variation ($P = 0.392$) between the means of the two sowing dates for panicle number per ha. However, this may have been due to the significant ($P = 0.041$) interaction of the sites and sowing dates for this trait. Tillering increased moderately and non-significantly in the second sowing date at the more fertile, unprotected site. This was perhaps due to earlier flowering there resulting in relatively small sink sizes of the first-flowering tillers. Plants then could have produced more sink capacity by producing a large number of effective tillers. This is consistent with the observed delayed flowering (due to lower inherent soil fertility) in the protected site resulting in a reduction panicle numbers per ha. Moreover, there were significance differences ($P = 0.034$) between the genotypes for number of panicles per ha indicating that genotypes had different potential for tillering and fertile tillers, but none of the interaction terms involving genotype treatments were significant.

Comparisons of genotypes using L.S.D. (17214) for number of panicles per ha was done (Table 2.12). Across sowing dates and bird scaring treatments, the early-flowering ICMV 155 e_1e_1 version of ICMV 155 consistently had higher numbers of panicles per ha than all entries except the ICMV 155 TCP (which was also relatively early flowering). No other significant differences between genotype means were detected for this character.

There was no significant variation ($P = 0.392$) between the means of the two sowing dates for panicle number per ha. However, this may have been due to the significant ($P = 0.041$) interaction of the sites and sowing dates for this trait. Tillering increased moderately and non-significantly in the second sowing date at the more fertile, unprotected site. This was perhaps due to earlier flowering there resulting in relatively small sink sizes of the first-flowering tillers. Plants then could have produced more sink capacity by producing a large number of effective tillers. This is consistent with the observed delayed flowering (due to lower inherent soil fertility) in the protected site resulting in a reduction panicle numbers per ha. Moreover, there were significance differences ($P = 0.034$) between the genotypes for number of panicles per ha indicating that genotypes had different potential for tillering and fertile tillers, but none of the interaction terms involving genotype treatments were significant.

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Table 2.13: Analysis of variance of panicle yield (kg ha^{-1}) in Experiment 2.

Source of variation	d.f.	S.S.	%SS	M.S.	v.r.	F pr.
Rep stratum	2	2.496E+06	61.8%	1.248E+06	31.10	
Rep.Scare stratum						
Scare	1	1.706E+07	12.0%	1.706E+07	425.30	0.002 **
Residual	2	8.023E+04	0.1%	4.012E+04	0.04	
Rep.Scarer.Sdate stratum						
Sdate	1	7.971E+06	5.6%	7.971E+06	8.70	0.042 *
Scarer.Sdate	1	8.163E+075	7.5%	8.163E+07	89.14	<.001 ***
Residual	4	3.663E+06	1.6%%	9.157E+0	5.06	
Rep.Scarer.Sdate.Gtype stratum						
Gtype	8	5.966E+06	4.2%	7.457E+05	4.12	<.001 ***
Scarer.Gtype	8	2.559E+06	1.8%	3.199E+05	1.77	0.100 NS
Sdate.Gtype	8	2.777E+06	2.0%	3.471E+05	1.92	0.072 NS
Scarer.Sdate.Gtype	8	6.143E+06	4.3%	7.678E+05	4.24	<.001 ***
Residual	64	1.158E+07	8.2%	1.810E+05		
Total	107	1.419E+08				

Table 2.14: Ranked genotypes of panicle yield (kg ha^{-1}) of the nine near-isogenic pearl millet genotypes in two sowing dates at sites with bird scaring and without bird scaring (Genotypes: 1 = ICMV 155, 2 = ICMV 155 TCP, 3 = ICMV 155 *bmr*, 4 = ICMV 155 *Bmr*, 5 = ICMV 155 Bristled, 6 = ICMV 155 e_1e_1, 7 = ICMV 155 E_1E_1, 8 = ICMV 155 early, 9 = ICMV 155 late; Sowing dates: SD1 = 25 June, SD2 = 9 July); Patancheru, rainy season 1998.

	Without Bird Scarers		**With bird Scarers**	
Rank	**SD1**	**SD2**	**SD1**	**SD2**
1	7(2526.2)	7(4928.6)	**5(3326.2)**	2(2302.4)
2	**5(2473.8)**	8(4657.1)	7(3019.0)	**5(1857.1)**
3	3(2273.8)	1(4571.4)	9(3011.9)	4(1761.9)
4	4(1854.8)	9(4454.8)	8(2945.2)	8(1673.8)
5	1(1797.6)	2(4228.6)	6(2907.1)	3(1576.2)
6	9(1735.7)	**5(4123.8)**	2(2854.8)	7(1514.3)
7	2(1557.1)	4(3959.5)	1(2839.1)	9(1497.6)
8	8(1519.0)	6(3866.7)	3(2135.7)	1(1411.9)
9	6(1369.0)	3(2902.4)	4(2611.9)	6(1295.2)
Mean	1905	4188	2850	1655

BS treat means - 3047   2252

SD means   2377 kg   2922 kg

L.S.D. = 347

Panicle Yield

There were highly significant differences (P = 0.002) between the sites with and without bird scarers for panicle yield (Table 2.13 and 2.14). The mean of panicle yield in the unprotected field was 3047 kg ha^{-1} and in the protected field was 2252 kg ha^{-1} indicating that the field sites had a significant influence on panicle yield. This was probably due to inherent differences in soil fertility between the two sites rather than a direct effect of bird scaring per se as the mean panicle yield in sowing date 1 (when bird pressure was greatest) was less in the unprotected plots (as expected) than in the protected plots.

There were significant differences (P = 0.042) between sowing dates in panicle yield. The mean of sowing date 1 was 2377 kg ha^{-1} and sowing date 2 was 2922 kg ha^{-1} showing that in sowing date 2 panicle yield was higher than sowing date 1. This was due to the fact that there was a lot of bird pressure during the first sowing date, especially in the field without bird scarers.

The interaction of bird scarer and sowing date treatments was highly significant ($P <$ 0.001) for panicle yield. In the unprotected field, grain damage by birds was substantial in the first sowing date, causing grain yield (and thereby panicle yield) to be lower in this date. In the protected field however, delayed flowering in the second sowing (due to soil compaction and crusting at emergence and lower soil fertility due to leaching of the basal fertilizer application) resulted in grain yields (and therefore panicle yields) lower than the first sowing date even in the absence of bird damage.

There were highly significant differences ($P <$ 0.001) between the genotypes for panicle yields as a result of genotypic differences in yield potential and vulnerability to bird damage.

The interaction of bird scarer and genotype treatments was not significant (P = 0.100) for panicle yield showing that this interaction did not influence on the weight of the panicle per ha. Similarly, the interaction between sowing date and genotype was not significant ($P = 0.072$) for panicle yield indicating that on average, genotypes behaved similarly for this trait across the two sowing dates. However, the interaction of bird scarers x sowing dates x genotypes was highly significant ($P < 0.001$) for panicle yield indicating genotype means should only be compared with the context of a given combination of site (with inherent soil fertility differences confounded with bird scarer treatments) and sowing date.

Comparison of genotypes using L.S.D. (347) for panicle yield was made (Table 2.14). The ICMV 155 Bristled genotype in the field without bird scarers, sowing date 1, was compared with other genotypes under these conditions. It was observed that despite its relatively early flowering date (and greater exposure to damage by birds in this environment) the panicle yield of the ICMV 155 Bristled genotype was not significantly different from that of the later flowering ICMV 155 E_1E_1 and ICMV 155 *bmr*. This indicates that the ICMV 155 Bristled genotype suffered less bird damage, allowing it to be among the high yielding varieties in this environment.

The ICMV 155 Bristled genotype in the field without bird scarers, sowing date 2, had a significantly lower panicle yield than genotypes ICMV 155 E_1E_1, ICMV 155 early and ICMV 155 (original). This indicated that performance of the ICMV 155 Bristled genotype was influenced by the sowing date to some extent for this trait and that it had a lower panicle yield potential under these conditions than this group of later-flowering entries.

In the field with bird scarers, sowing date 1, the ICMV 155 Bristled genotype had the numerically highest panicle yield, but it was not significantly different from ICMV 155 E_1E_1 and ICMV 155 late for this character. However, ICMV 155 Bristled had significantly higher panicle yield than all other entries in this environment. This indicates that the ICMV 155 Bristled genotype had a reasonably good panicle yield under these conditions. Moreover, the ICMV 155 Bristled genotype in the field with bird scarers, sowing date 2, had panicle yield significantly lower than genotypes

ICMV 155 TCP, significantly higher than ICMV 155 late, ICMV 155 (original) and ICMV 155 e_1e_1 and was on par for this trait with other entries. This also indicated the ICMV 155 Bristled genotype had a reasonable panicle yield under these conditions.

Table 2.15. Summary of performance of the nine pearl millet near-isogenic varieties in the background of elite cultivar ICMV 155, with and without bird scaring (confounded with inherent soil fertility), in the first sowing date at Patancheru, 1998 rainy season.

a)

		Grain yield	Diff(%) relative	Stover Relative Yield	Diff (%)	Panicle yield	Diff(%) relative	Panicle threshing %	
Bird scarer	**Genotype**	**kg ha $^{-1}$**	**% of G/mean**	**Kg ha $^{-1}$**	**% of G/mean**	**Kg ha $^{-1}$**	**% of G/mean**	**Absolute**	**% of mean**
Present	Original ICMV 155	2090	-3.55	3720	-8.00	2840	-0.32	73.7	-2.90
	TCP	2170	0.13	4330	7.13	2850	0.04	76.2	0.40
	bmr	1560	-28.01	3600	-10.94	2140	-24.89	73.3	-3.43
	Bmr	1980	-8.63	4170	3.17	2610	-8.39	75.6	-0.40
	Bristled	**2570**	**18.60**	**4210**	**4.16**	**3330**	**16.88**	**77.3**	**1.85**
	e_1/e_1	2250	3.83	3340	-17.37	2910	2.14	77.4	1.98
	E_1/E_1	2320	7.06	5150	27.41	3020	6.00	76.9	1.32
	Mass selected early	2260	4.29	4020	-0.54	2940	3.19	76.9	1.32
	Mass selected late	2290	5.68	3860	-4.50	3010	5.65	76.2	0.40
	Mean	**2167**		**4042**		**2849**		**75.9**	
	L.S.D	**466**		**642**		**543**		**0.36**	
Absent	Original ICMV 155	1020	-8.68	7630	-0.26	1840	-3.46	55.1	-3.67
	TCP	870	-22.11	7140	-6.67	1560	-18.15	55.7	-2.62
	bmr	1490	33.39	7110	-7.06	2280	19.62	65.6	14.68
	Bmr	1100	-1.52	7910	3.40	1860	-2.41	59.2	3.50
	Bristled	**1650**	**47.72**	**7330**	**-4.18**	**2480**	**30.12**	**66.8**	**16.78**
	e_1/e_1	610	-45.39	7480	-2.22	1370	-28.12	44.9	-21.50
	E_1/E_1	1660	48.61	8220	7.45	2530	32.74	65.8	15.03
	Mass selected early	780	-30.17	7500	-1.96	1520	-20.25	51.3	-10.31
	Mass selected late	880	-21.22	8570	12.03	1740	-8.71	50.6	-11.54
	Mean	**1117**		**7650**		**1906**		**57.2**	
	L.S.D	**432**		**479**		**339**		**2.98**	

b)

Total dry matter (stover + panicle yield)	Diff(%) Relative	Plant population		Plant height	Diff(%) Relative	Time to 75% flowering	Diff (%) Relative	% bird damage to panicle	Diff(%)
Kg ha $^{-1}$	% of G/mean	000 plts ha $^{-1}$	% of G/mean	cm	% of G/mean	Days	% of G/mean	Mean	% of G/mean
6560	-4.79	129	1.57	223.0	-0.34	49.0	1.45	*	*
7180	4.21	123	-3.15	227.7	1.76	47.7	-1.24	*	*
5730	-16.84	124	-2.36	215.7	-3.60	52.3	8.28	*	*
6780	-1.60	128	0.79	228.7	2.21	49.3	2.07	*	*
7530	**9.29**	**131**	**3.15**	**225.0**	**0.55**	**46.0**	**-4.76**	*	*
6240	-9.43	133	4.72	205.0	-8.38	41.7	-13.66	*	*
8170	18.58	119	-6.30	244.3	9.18	53.7	11.18	*	*
6970	1.16	127	0.00	216.7	-3.16	47.3	-2.07	*	*
6870	-0.29	129	1.57	227.7	1.76	47.3	-1.99	*	*
6890		**127**		**223.76**		**48.3**		*	*
1140		**16.5**		**13.2**		**2.899**		*	*
9480	-0.84	107.1	-1.83	277.0	5.08	47.3	0.21	61	9.91
8700	-9.00	110.3	1.10	260.0	-1.37	47.0	-0.42	59	6.31
9380	-1.88	106.3	-2.57	254.7	-3.38	48.7	3.18	46	-17.12
9760	2.09	104.8	-3.94	270.0	2.43	48.3	2.33	56	0.90
9800	**2.51**	**111.9**	**2.57**	**264.0**	**0.15**	**45.7**	**-3.18**	**38**	**-31.53**
8850	-7.43	100.8	-7.61	235.0	-10.85	44.7	-5.30	69	24.32
10750	12.45	113.5	4.03	279.3	5.96	50.0	5.93	37	-33.33
9020	-5.65	119	9.07	267.3	1.40	47.0	-0.42	70	26.13
10300	7.74	107.9	-1.10	265.3	0.64	46.3	-1.91	64	15.32
9560		**109.1**		**263.6**		**47.2**		**55.5**	
405		**13.805**		**13.06**		**1.329**		**8.9**	

The summary of performance of the nine pearl millet near-isogenic varieties in the background of elite cultivating ICMV 155, with and without bird scaring (confounded with inherent soil fertility) in the first sowing date of this experiment is showed in Table 2.15. When the ICMV 155 Bristled genotype was compared with the other genotypes in the field with bird scarers, it had the highest grain yield (18.6% above grand mean) and was followed by genotype ICMV 155 E_1E_1. In the field without bird scarers, ICMV 155 E_1E_1 had the highest grain yield in this sowing date followed by the ICMV 155 Bristled genotype (47.7% above the grand mean). This confirms that the ICMV 155 Bristled genotype was one of the highest yielding genotypes in this sowing date, whether or not the crop protected from birds.

The panicle threshing percentage is obtained by dividing grain yield by panicle yield and multiplied by 100. In the plots with bird scarers, the ICMV 155 e_1e_1 genotype had a higher threshing percentage (77.4%) and it was followed by the ICMV 155 Bristled genotype (77.3%), the ICMV 155 mass-selected early genotype (76.9%) and the late flowering ICMV E_1E_1 genotype (76.9%). In the field without bird scarers, the highest threshing percentage was that of the ICMV 155 Bristled genotype (66.8%) followed by ICMV 155 E_1E_1 (65.8%) and ICMV 155 *bmr* (65.6%). The higher the panicle threshing percentage, the less the degree of damage to the panicles caused by feeding birds.

For the character total dry matter (stover + panicles) yield in the field with bird scarers, the highest genotypic mean was that of late-flowering ICMV 155 E_1E_1 (8.2 t ha^{-1}) and followed by the ICMV 155 Bristled genotype (7.5 t ha^{-1}). However, in the field without bird scarers the ICMV 155 Bristled genotype had even higher total dry matter yield 9.8 t ha^{-1} although this was less than of ICMV 155 E_1E_1 (10.7 t ha^{-1}) and mass-selected ICMV 155 late variety (10.3 t ha^{-1}).

In the character plant population observed in the field with bird scarers, the highest population density was observed for ICMV 155 e_1e_1 (133,000 plants ha^{-1}) and followed by the ICMV 155 Bristled genotype (131,000 plants ha^{-1}). In the field without bird scarers, the highest number of plants per ha was observed for the ICMV 155 mass-selected early (119,000 plants ha^{-1}), followed by ICMV 155 E_1E_1 (113,500 plants t ha^{-1}), and ICMV 155 Bristled (111,900 plants ha^{-1}) genotypes. It could be said the ICMV 155 Bristled genotype had reasonable crop establishment.

For the character of plant height in the field of with bird scarers, ICMV 155 E_1E_1 was the tallest (244 cm) followed by genotypes of ICMV 155 *Bmr* (229 cm), ICMV 155 mass-selected late (228 cm), ICMV 155 TCP (228 cm) and ICMV 155 Bristled (225 cm). In the field without bird scarers, ICMV 155 E_1E_1 (279 cm) genotype was the tallest, followed by the genotypes ICMV 155 (Original) (277 cm), ICMV 155 *Bmr*

(270 cm), ICMV 155 mass-selected early (267 cm), ICMV 155 mass-selected late (265 cm) and ICMV 155 Bristled (264 cm). It can be said ICMV 155 Bristled genotype was medium in nature for the character plant height.

For the character time to 75% flowering in plots both with and without bird scarers, the shortest time was require by the early flowering genotype ICMV e_1e_1 (41.7 and 44.7 d) followed by the ICMV 155 Bristled genotype (46.0 and 45.7 d), respectively. This indicated that these two genotypes were the best ones for early maturity.

In the field without bird scarers, bird damage was least on late-flowering genotype ICMV 155 E_1E_1 (37%) followed by early-flowering ICMV 155 Bristled (38%), and late-flowering ICMV 155 *bmr* (46%). This indicted that these were the three least affected by birds. Of these three, ICMV 155 Bristled had 17% less damage than ICMV 155 *bmr*, while flowering at essentially the same time, and thus being exposed to similar pressure from grain feeding birds.

5.0. DISCUSSION AND CONCLUSIONS

5.1. Discussion and conclusions for Experiment 1

The experiment was conducted under normal and extended day lengths with two sowing dates and high and low fertility levels at the ICRISAT research farm at Patancheru, Andhera Pradesh, India. The main objective of the experiment was to investigate in both day lengths the effect of the major gene e_1 on flowering dates (75%), grain yield, total dry matter, panicle number and panicle yield.

Grain yield is one of the most important characters that subsistence farmers in arid and semi-arid areas are interested for. However, grain yield is influenced by many factors such as day length, soil fertility, sowing dates, daily hours of bright sunshine, varieties, etc.

Pearl millet in this experiment is a short day plant with crop duration normally affected by day length. However, there was no variation for grain yield per ha between normal and extended day lengths because there was rainfall through out the season so later-flowering plots did not face terminal drought stress. Had there been shortage of rainfall at the end of the crop growing period, the late maturing plants could not have escaped the dry conditions. Had rainfall shortage occurred, the results from this experiment might have agreed to those of Andrews and Kumar (1992) where grain yield was affected by environmental factor (photoperiod) .

Early sowing can be used as a strategy to escape biotic and abiotic factors that negatively affect grain yield. Sowing date variation can also influence grain yield. A difference of 15 days between the first and the second sowing dates had a significant effect on the grain yield. This agrees with the findings of Maiti and Soto (1990) who reported that sowing date had significant effect on time required from emergence to panicle initiation. Sowing date 1, which was early (25 June), had very high mean grain yield compared to sowing date 2 (9 July). This agrees with the findings of Hawlader and Islam (1991) who conducted their experiment on foxtail millet, and disagrees with Nelson (1990) who found lower grain yield for proso millet sown between 15 June to 1 July. The observed result in the current study can be greatly explained by the plants taking advantage of the first rain and dry sunny conditions after seedling emergence. Further, long day lengths in this first sowing date could have marginally delayed flowering (allowing production of increased pre-flowering biomass) compared to the second sowing date.

One of the additional factors that can increase grain yield is fertility status of the soil. From this experiment, the plots receiving the higher fertility treatment gave more than double the grain yield of those with the low soil fertility treatment. The application of fertilizer side-dressing helped the crop to maintain growth following the good start provided by the basal fertilizer application. This permitted the side-dressed plots to attain better growth rate across the full growth season as compared to those in plots that did not receive the N side-dressing treatments that was reflected on the total grain yield. This agrees with the investigation of Rao and Nambiar (1952). From their observation, fertilization application offered great potential for improving grain yield.

In the current experiment, it was observed that sowing date and nitrogen side-dressing treatments showed an interaction. The combination of the right sowing date with the optimal fetritilizer rate almost doubled grain yield in the sowing date 1, high fertility environments as compared to those obtained in the sowing date 2, low soil fertility environments.

Genotype variation has also showed a very high significant difference for grain yield. The earliest variety (ICMV 155 e_1e_1) obtained a reasonable yield as compared to late-flowering varieties. This agrees with the findings of El Hag Hassan Abuelgasaim (1992) who observed in his experiment that early-maturing varieties gave better yield compared to late-maturing ones. Moreover, there was significant difference for grain yield as the genotypes interacted with sowing dates which agrees with the investigation of Maiti and Soto (1990). In this interaction in sowing date 1, genotypes perform better than sowing date 2. Genotype ICMV 155 e_1e_1 yielded as well as any of the high yielding varieties in both sowing dates.

In this experiment, the factor photoperiod did not significantly interact with any of the other factors such as genotypes, sowing dates and soil fertility treatments.

In arid and semi-arid agriculture, it can be said that late maturing varieties are often the ones most affected by drought and other factors. The character grain yield, therefore, will be definitely affected by this factor. In this experiment, it was observed that the late flowering varieties such as ICMV 155 *bmr* and ICMV 155 E_1E_1 gave the lowest grain yields.

The second important crop character considered was the total dry matter production. The pearl millet crop is generally photoperiod sensitive and as the day length gets longer, the time required for it to reach maturity will also be longer. In this experiment there were significant differences for total dry matter between the normal and extended day lengths. The total dry matter produced in the extended day length was higher than in the normal day length. This agrees with findings of Begg and Burton (1971), who observed higher total dry matter yield in the experiment of short day pearl millet conducted under extended photoperiod. One reason could be the number of tillers was higher in longer day length. This agrees with finding of Ong (1983) who suggested that growth increased many tillers will be produced and continue to grow for longer period which finally can influence the total dry matter yield. As maturity was delayed, further vegetative growth was initiated with available photosynthate instead of using these resources to develop panicles earlier and fill grain in them.

Sowing date difference was another factor that contributed to variation in total dry matter production. Due to the difference in sowing dates there was variation in growth environments experienced by the crop. There was a soil compaction and crusting problems in the second sowing date (due to mechanical sowing into soil that was too wet). Even so, it was observed that there was growth variation between sowing date 1 and sowing date 2. This could be due to the crop in sowing date 1 having better utilized early rainfall and escaped from natural hazards at the later growth stages resulting in better vegetative growth. It could also be explained in part by detrimental effects of the soil compaction/crusting on seedling establishment and early seedling growth in the second sowing date, combined with leaching of soil nutrients (from both the basal fertilizer dose natural mineraliztion) by rains received prior to the second sowing date.

Vegetative growth was influenced by treatments affecting fertility status of the soil. From the experiment, it was observed that there were clear differences between the low and high soil fertility treatments (without and with nitrogen side-dressing, respectively). The plots that were top-dressed produced almost two times the total dry matter compared to those that were not top-dressed. This agrees with the findings of ICRISAT (1985) that application of N as side-dressing resulted in higher total dry matter yield.

Further, as the nitrogen level (side-dressing treatment) interacted with sowing date, a significant variation for total dry matter yield was observed. In the combination of sowing date 1 and high fertility level treatment, the highest total dry matter yield was observed.

The total dry matter production was also influenced by genotypic variation among the near-isogenic versions of pearl millet variety ICMV 155. It was apparent that the earliest variety gave lower total dry matter yields while the later-flowering varieties gave higher total dry matter yields. Moreover, as the genotypes interacted with nitrogen level a significant variation for total dry matter was observed. The latest-flowering genotype at high fertility level produced the highest total dry matter yield.

In this experiment, pearl millet behaved like a short day plant in which flowering is delayed by extended photoperiod. As the day length got longer, the time to maturity was also extended. Plants grown under longer day lengths required longer period to reach maturity. This agreed with Burton (1965), Begg and Burton (1971), Burton (1981) and Wallace et al. (1993a) who observed longer days in pearl millet have delayed flowering time of the crop.

Time to 75% flowering was also affected by the differences in sowing dates. Plants sown in sowing date 1 bloomed earlier than sowing date 2, which was reflected in the time required to reach maturity. This was somewhat unexpected as the shorter natural day lengths in sowing date 2 were expected to induce earlier flowering. However, it appears that heavy rainfall between the two sowing dates caused enough leaching of soil nutrients to overcome this expected effect of delayed sowing. The earliest genotype in both sowing dates was ICMV 155 e_1e_1.

The treatments intended to directly affect levels of soil fertility have also influenced the time to 75% flowering. In this experiment it was observed that there was highly significant difference between the high and low fertility level treatments (obtained with and without nitrogen side-dressing, respectively). Plants grown under the high fertility level bloomed earlier than those in the low fertility treatment (without nitrogen side-dressing). From this it can be said that by applying optimal level of fertilizer, the days required to maturity can be shortened and plants can escape from natural hazards like terminal drought stress, pests and diseases. The genotype ICMV 155 e_1e_1 ranked first to flower in both low and high soil fertility conditions.

Moreover, genotypic variation also influenced the time required to reach to 75% flowering. From this experiment, it was observed that there was highly significant difference for time 75% to bloom between the genotypes. This agrees with the findings of Maciel et al. (1995) which was conducted in the semi-arid environment of Brazil. Further, there was significant genotype x day length treatment interaction for flowering time. Most of the genotypes were affected by the extended day length treatment, but ICMV 155 e_1e_1 was the least affected by the extended day length treatment in which this early genotype reach 75% flowering in 49 days under normal day lengths and 51 days in extended day lengths. This supports the findings of Hanna and Burton (1985) in an experiment conducted to see the effect of morphological and genetics of two mutations for early-maturing in "Tift 23" pearl millet. The e_1 gene conditioned the crop to mature 11 to 14 days earlier than its isogenic early (ICMV E_lE_l) counter part under both normal and extended day lengths which supports the findings of Burton (1981). This photoperiod-insensitive early flowering will help the crop to mature in a shorter duration and escape from natural hazards such as drought, pests and diseases.

In the interaction of genotypes with photoperiod, sowing date, and nitrogen level, a significant variation for time to 75% flowering was observed. By selecting the right genotypes and day lengths, it is possible to shorten the time required to reach maturity. In both normal and extended day lengths, genotype ICMV 155 e_1e_1 bloomed the earliest among the nine genotypes. Selection of sowing dates and genotypes had also influenced days required for this character, with ICMV 155 e_1e_1 again flowering earlier than other genotypes, regardless of sowing date. Further, fertility rate and genotype selection are important factors for shortening the maturity days, and flowering of ICMV 155 e_1e_1 genotype was delayed to a lesser degree by the low fertility treatment than were other entries. Thus the e_1 gene reduces sensitivity of flowering to nitrogen deficiency as well photoperiod. This is perhaps the most important finding of this experiment.

The character plant height was influenced by many growth factors. One of them was day length. In the experiment conducted, there were highly significant differences between the normal and extended day length treatments for this character. Plants grown under the extended day lengths had greater plant height than the plants grown under the normal day lengths. This agrees with the investigation of Begg and Burton (1971) who observed the effect of extended day length on time taken to anthesis and plant height. This was because of longer day lengths prevented most genotypes from initiating panicle development until the plants had grown taller. However, the ICMV 155 e_1e_1 genotype was early-flowering and not as sensitive to day length as others, or as tall as other genotypes in both day length treatments.

Plant height was also influenced by the date of sowing (that appears to have been confounded with soil fertility and photoperiod treatment) in this experiment. The plants sown in sowing date 1 had greater plant height than plants of sowing date 2. This disagrees with the findings of Nelson (1990) in proso millet that indicated delaying sowing from 15 June to 1 July resulted in shorter plant height. The result in the current experiment was due to a better growth conditions observed during the first sowing time. During sowing date 2, there were some problems such as soil crusting and high soil moisture after seedling emergence, as well as pre-sowing leaching of naturally occurring mineralized nitrogen and the basal fertilizer application. These contributed to the shorter heights and lower yields observed in the second sowing date.

The application of a fertilizer side-dressing directly affected plant heights. Plants grown in higher soil fertility reached a greater plant height than plants grown under lower soil fertility (fertility differences due to application or non-application of the nitrogen side-dressing treatment). Genotype ICMV 155 e_1e_1 responded the least to soil fertility variation provided by the side-dressing treatments. Moreover, the interaction of sowing date and nitrogen side-dressing application was highly significant for plant height. The combination of sowing date 1 with the nitrogen side-dressing attained higher plant height.

Genotype variation was also a factor that contributed to plant height differences, accounting for 3% of the variation observed for this character in Experiment 1 (Table 1.9). In this experiment, the late-flowering varieties attained greater height where as the earliest genotype was the shortest. Further, as the genotypes interacted with photoperiod, a great variation for plant height was observed. Most genotypes in the extended day length treatments attained greater plant heights than when grown under normal day lengths. The highest increment percentage was attained by ICMV 155 *Bmr* (38.7%) the least increment percentage was by ICMV 155 e_1e_1 (18.1%).

In the interaction of genotypes with nitrogen side-dressing application treatments, genotypes grown under high soil fertility had greater heights than when the same genotypes were grown in low soil fertility. Moreover, the combination of the first sowing date, high soil fertility and late-flowering genotypes gave the greatest plant heights. Late varieties responded more than early variety to both sowing date and soil fertility treatments. The early-flowering entry ICMV 155 e_1e_1 was less responsive to both sowing date and nitrogen side-dressing than other genotypes.

The character plant numbers per ha was related to plant establishment. In the experiment, there was a significant difference between densities under normal and extended days. The plants under normal day length established better than the plants in the extended day length. This was primarily due to the confounding of sowing method (mechanized sowing vs. manual sowing) with day length treatment in the second sowing date of this experiment.

Sowing date difference had also influenced the crop establishment. Sowing date 2 had a crusting problem in both day length treatments and serious soil compaction problems in the normal day length treatment due to sowing by machine before the soil was dry enough. Due to this reason, the number of plants per plot in sowing date 1 was higher than sowing date 2. Further, it was observed that plots in the extended day length areas of sowing date 1 had higher numbers of plants per ha. However plots in the normal day length areas of sowing date 2 were highly affected by soil compaction, consequently the number of plants per plot was reduced in this set of treatments.

The number of panicles varied as a result of sowing dates, side-dressing treatments, and genotype differences. The number of panicles was not significantly affected by the two day length treatments. However, there was a highly significant difference for this trait between the two sowing dates. This difference was attributed to the crusting problem faced during sowing date 2. Further, on average plants had higher numbers of panicles in sowing date 1 under normal day lengths than in other sowing date x day length treatment combinations.

Soil fertility differences provided by the side-dressing treatments also influenced the number of panicles per ha. The plots with higher soil fertility conditions had higher numbers of panicles than those in low fertility conditions. This was due to the effect of nitrogen side-dressing applied to the soil and initiated production of a larger number of productive panicles that in turn was reflected at higher grain yield. This finding agrees with Mangath (1987) that reported grain yield increased with the increase of N applications, mainly resulted due to increased panicle numbers.

Further, the number of panicles was influenced by genotype variation. There were highly significant differences between genotypes and the greatest panicle number was observed for ICMV 155 e_1e_1, the earliest flowering genotype. In the interaction of genotype with photoperiod, it could be said that the ICMV 155 e_1e_1 had the smallest reduction in numbers of panicles in response to extended day lengths (Table 1.5).

Panicle yield is determined by the number of fertile tillers and panicle lengths, grain size and compactness of the panicles. From the experiment, it was observed that sowing date 1 provided almost twice the panicle yield of sowing date 2. This could be due to good growth conditions of sowing date 1 that resulted in higher and productive tillers. Longer normal day lengths, greater availability of soil nutrients (because they had not been leached by pre-sowing rains), and reduced problems with soil compaction and crusting all probably contributed to the more favorable conditions for crop growth in sowing date 1.

The higher rate of nitrogen availability, provided via a nitrogen side-dressing, initiated the production of larger number of productive panicles. Plants grown in higher soil fertility produced twice the number of panicles as those grown in lower fertility conditions. Moreover, as nitrogen and sowing date combined at optimal levels, still higher number of productive tillers could be obtained. From the experiment, the highest panicle yields were observed in sowing date 1 plots that received the nitrogen side-dressing treatment.

Genotypes were also a factor that contributed to panicle yield differences. While the earliest flowering genotype (ICMV 155 e_1e_1) was one with the greatest potential to produce higher number of panicles per ha, the smaller individual mass of these panicles meant that this did not translate into the highest panicle yields.

The development of genotypes with the e_1 gene can produce pearl millet that is photoperiod insensitive and early flowering regardless of soil fertility status, that can grow and mature in the shortest possible period. In combination with optimal sowing dates and soil fertility rate, the genotypes can be useful as means of escaping drought, pests and disease in areas where a predominantly rain-fed crop is grown and the duration of the favourable moisture regime is limited. If such photoperiod and soil fertility insensitive pearl millet genotypes can be developed, they will make it possible to grow pearl millet not only in the tropics, but also in temperate areas for different purposes such as human food and animal feed.

5.2.Discussion and conclusion for experiment 2

Experiment 2 was conducted to determine the effects of backcross transfer of long panicle bristling into elite open-pollinated pearl millet variety ICMV 155 on grain and stover yield potential and on vulnerability of grain produced to bird damage.

Pearl millet in most cases is considered an early crop that matures before other crops starts to mature. This contributes to its constantly suffering from bird damage. The most important birds in the area where the experiment was conducted were Roseringed parakeets (*Psittacula krameri* Scopli). Their roosting site was about one kilometer away from the experimental field. Since there was no other unprotected ripening grain crop in the vicinity at the time the first sowing date of this experiment reached grain filling stage, this pearl millet experiment (the unprotected plot without bird scarers) was the primary food source for these birds. Early in the morning and late in the evening was the critical time for the crop and the total number of birds feeding on it were estimated at about 5000 parakeets (Suhel Quader, pers. comm.; see Fig. 4).

The plots that were sown during the first sowing date were seriously damaged whereas plots of the second sowing were less damaged as other sources of grain had become available for the birds to feed on by the time these later-sown plots reached the critical grain-filling stage of crop growth. Thus the birds also began to feed on alternative fields nearby and the local population of birds was distributed in those fields as well. Regardless of genotype, almost all entries in the trial had reasonable grain yields in sowing date two in the relatively more fertile field, despite absence of protection from the bird menace.

This experiment had two treatments assigned to the main plots. These were with and without bird scarers. The bird scarer treatment was fully protected with bird scarers present starting from 6:00 am in the morning until 7:00 pm in the evening for both sowing dates. At the time of harvest, panicles were collected and the bird damage estimated visually. Damage was estimated to be 45.3 – 66.7% with the highest damage observed on the earliest variety, ICMV 155 e_1e_1 and probably accounts for extremely low grain yield from this entry in the first sowing date of the unprotected field. This observation agreed with finding of Parasharya et al. (1995) that observed 38.54 – 73.93% bird-damage in their sorghum experiment grown under isolated and unprotected field conditions.

Ripening pearl millet in the unprotected fields was damaged by parakeets to a great extent. While feeding, these birds wasted much grain that they dropped while gnawing on the panicles. It was observed that the soil surface of the unprotected field was covered with pieces of developing grains that were dropped by birds while feeding. This agreed with the observations of Ali and Futehally (1967) who reported that parakeets are very destructive to crops and waste more than they consume.

In this experiment a genotype with long panicle bristles, ICMV 155 bristled was tested for its resistance to bird damage compared to near-isogenic genotypes lacking these bristles. When the bristled genotype was evaluated, it performed well in resisting the bird damage, i.e., the bristling gene (*Br*) expressed well in protecting grain from bird damage under free choice feeding conditions. It was also comparable in grain yield with two other genotypes that had less damage: the first was a late-flowering variety with E_1 gene and the second genotype was with the later-flowering genotype with the brown mid-rib gene, which had lodging problems (panicles bending below the top of the crop canopy). In spite of the heavy bird pressure that the earlier flowering ICMV 155 Bristled genotype experienced, it suffered less from the bird damage than the non-bristled genotypes. This finding is perhaps in contradiction to observations by Doggett (1988) that no single character was observed to reduce bird damage effectively in sorghum, although the other genotypes available to the birds in this experiment were at least partially responsible for this discrepancy. However, it is difficult to say whether the ICMV 155 Bristled genotype would resist bird damage as effectively (by no means completely) in the absence of other ripening genotypes in the same field or adjacent fields, especially when birds were hungry at the beginning of the season, as it was observed by Elliot (1987) that it is difficult to develop a variety that will completely left attacked by birds when they are hungry.

In this experiment, it could be said that crop loss due to bird damage was relatively low for the ICMV 155 Bristled genotype because the presence of the bristles may not be comfortable for the birds and the developing seeds are protected from being eaten to some extent. This finding agreed with Beri et al. (1969) who found genotypes with awns were less damaged by birds than those without awns, but disagreed with Beesley and Lee (1979) who got high seed loss even with the bird-resistant variety. However, visual estimates of losses from panicles of the ICMV 155 Bristled genotype in the first sowing date of Experiment 2 in the current study were still serious, averaging 46%. This could be because birds did not have any ripening field as alternative during the first sowing date. Under such condition, birds will eat any type of seed and the damage can be serious (Sarwar and Murty, 1982).

The extent of bird damage in the protected field was not significant. The expectation of higher yield in this field due to its being fully protected from birds was off-set by other problems observed (primarily the lower level of inherent soil fertility due to differences in cropping history of the two fields).

Plant height as a character could have an influence on vulnerability to bird damage under the free choice conditions of this trial and on the total dry matter. When the ICMV 155 Bristled genotype was evaluated for this character, it had medium plant height and could not be said to have escaped from bird damage due to its short height. Therefore, its escape from bird damage must be attributed to the presence of long panicle bristles and its higher total dry matter could also be influenced by its medium plant height (actually early for its flowering date). However, the genotype with the brown mid-rib trait had a relatively short height, late flowering, and a lodging problem. The cumulative effect of these three factors could have resulted in the lower bird damage observed on this genotype. In this case, plant height (or at least the height of panicles resulting from the combination of shorter plant and bending stems) of ICMV 155 *bmr* could have combined to reduce the vulnerability of this genotype to bird damage. This observation agrees with the findings of ICAR (1968) in which dwarf cultivars seem less susceptible to bird attack in fields with taller varieties.

It is evident that the performance of almost all dryland crops is influenced by the erratic nature of rainfall. As a mechanism for escape from drought, pests and diseases early flowering and maturity must be considered as an option in order to get a reasonable grain yield. When the ICMV 155 Bristled genotype was evaluated for time to 75% flowering, it was found to be among the early-flowering genotypes. Therefore, it could that be said that the ICMV 155 Bristled genotype required a shorter period than the original ICMV 155 (its recurrent parent) for grain production. Despite earlier maturity, the *Br* gene (for long panicle bristles) conferred some protection against bird damage.

Earliness on the one hand could help to escape drought, pests and diseases prevalence, on the other hand it could expose the grains to bird damage. In this experiment, it was observed that the ICMV 155 e_1e_1 genotype had flowered and matured earlier than any of the other genotypes under testing. Due to this reason, this genotype was damaged by birds at the highest observed level (66.9%).

Total vegetative dry matter production of the genotypes was evaluated after grain harvest. The ICMV 155 Bristled genotype was observed to be one of the highest yielding genotypes for total dry matter, in fact it was superseded for this trait only by the late flowering genotype ICMV 155 E_1E_1. This was a reflection of the good growth of the ICMV 155 Bristled genotype. In subsistence agriculture, the total vegetative dry matter yield (also referred to as 'stover') is often the second most important character used as a selection criteria next to grain yield for the reason that this non-grain biomass can be used as animal feed, construction material, or fuel. Besides the potential of ICMV 155 Bristled genotype to protect itself against bird damage, it also had a good potential for producing high total dry matter yield.

The optimal plant population per plot can be one of the important factors that contributes to grain yield and total dry matter production. The ICMV 155 Bristled genotype in sowing date 1 of both fields (with and without bird scarers) provided a good crop establishment compared to sowing date 2 of both fields. This could be attributed to the sowing date 1, providing environmental conditions more conducive for good seedling emergence and crop establishment. This contributed to the better crop establishment observed in sowing date 1 compared to sowing date 2. Plant number per plot could influence to the grain yield and total dry matter.

The total number of panicles per plot provides an estimate of the number of productive tillers for a given genotype. Moreover, this is also a determining factor and important component of both the grain yield and total dry matter production. When the number of tillers per plot was evaluated, the ICMV 155 Bristled genotype produced a reasonable number of fertile tillers in all the fields. This can be considered as a good character of the ICMV 155 Bristled genotype. The intermediate number of tillers of this genotype was reflected in the total grain yield and total dry matter, which were both found to be in the acceptable range.

Panicle yield is an easily measured descriptive character that shows the production of dry panicle mass (indicative of their grain yield), after harvest. It was observed that the ICMV 155 Bristled genotype had a reasonable panicle yield in both sowing dates and both fields. In sowing date 1 where there was heavy bird pressure, the ICMV 155 Bristled genotype was observed to be among the highest yielding entries. In sowing date 2, the ICMV 155 Bristled type had only moderately grain and stover yield compared with other genotypes in the same environment. Due to the non-preference type of bird damage resistance of the ICMV 155 Bristled genotype, it attained a higher panicle yield than non-bristled genotypes when bird pressure was heavy (in the first sowing date of the unprotected field). ICMV 155 Bristled was the numerically highest yielding genotype (for both grain and panicle yield) of the first sowing date in the field protected by presence of bird scarers, indicating that both yield potential per se and bird resistance conferred by its panicle bristles contributed to its high yield in the first sowing date of the unprotected field.

The ICMV 155 Bristled genotype under investigation for its possible resistance to bird damage showed reasonable potential to resist grain losses due to bird damage even under heavy pressure. This resistance was especially effective when birds had access to alternative food sources. The other characters observed, like total vegetative dry matter production, earliness, plant height, plant count, panicle count and panicle yield were all at acceptable levels for this ICMV 155 Bristled genotypes. Therefore, it can be said that the *Br* gene for long panicle bristles, present in the ICMV 155 Bristled genotype, could be useful if introduced into pearl millet grain cultivar for areas where there is a high level of grain loss due to bird damage.

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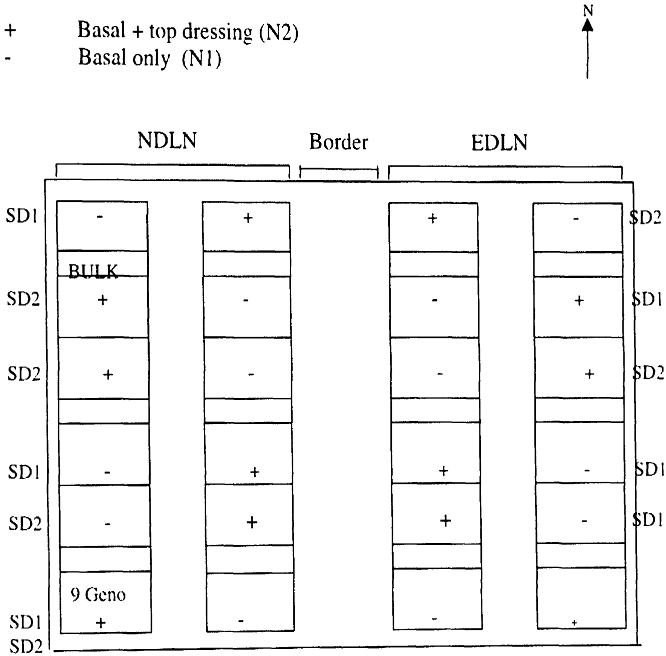
Annex 1.

LAYOUT OF EXPERIMENT 1

+ Basal + top dressing (N2)

- Basal only (N1)



Total area = 0.5 ha

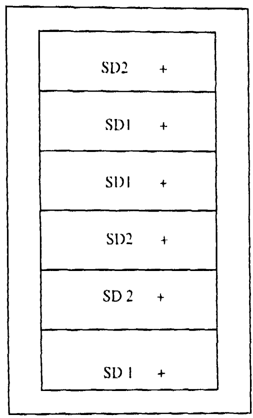
Experimental design – Split-split-split plot design

Annex 2.

LAYOUT OF EXPERIMENT 2

NDLN No Bird Scaring

\+ Basal + Topdressing (N2)



Total area = 0.052 ha

Experimental design – Split-split plot design