

EFFECT OF ALIEN CYTOPLASM ON YIELD AND YIELD COMPONENTS: A REVIEW

PATEL, J. B.*

DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY
JUNAGADH AGROCULTURAL UNIVERSITY
JUNAGADH - 362 001, GUJARAT, INDIA

**E mail: jbpatelvasai38@gmail.com*

Cytoplasmic genetic information has been ignored as a source of genetic diversity for a long time, which is surprising, given that the mitochondrion and chloroplasts are the major site of energy conversion in the cell and thus play a vital role in determining the overall performance and productivity of crop plants. The cytoplasmic diversity detectable within a series of distantly related varieties is thought to correspond to their nuclear divergence. This reflects nuclear cytoplasmic interactions which can be responsible for the breeding success. Usage of information about correlations between nuclear and organellar genomes could be important in order to optimize their compatibility.

Most, if not all of the major changes which occur during growth and differentiation of higher plants are associated with or dependent upon, marked changes in the number, structure and metabolic activity, of either one or both organelles (Topping and Lever, 1990). Plant mitochondrial genomes are generally large, multicircular and contain sequences of different stoichiometry. Evolution of these complex genomes appears to occur via reorganization of sequences rather than by point mutation. Within most crop species characteristic differences exist between their mitochondrial genome organisations. Many of these differences probably have no phenotypic consequence. However in specific lines some deviating phenotypes have been shown to be due to the modification of existing genes or the creation of novel genes by

aberrant intra- or inter- molecular DNA recombination events (Lossi *et al.*, 1999). These chimaeric genes are expressed as variant polypeptides, which in most cases are associated with the energy-transducing inner mitochondrial membrane, and appear to be causally related to male sterile phenotype or toxin sensitivity as shown for maize by Braun *et al.* (1989). The only cytoplasmically inherited trait which has been exploited by the plant breeder so far is cytoplasmic male sterility (CMS) which in most cases results from either, an incompatibility between the nuclear genome of one race or species and the mitochondrial genome of another, or specific mutations in the mitochondrial genome.

Chromosome theory of inheritance suggested that Mendelian factors or genes were located on chromosomes. This theory was proved to hold good through a variety of experimental evidences. Since the chromosome complement in male and female gametes obtained from same individual would be similar, reciprocal crosses should give same results. The only exception to this expectation, earlier studied in Sex Linked, Sex Influenced and Sex Limited Traits is sex linked inheritance. Differences in reciprocal crosses involving sex linked characters can be easily explained on the basis of transmission of sex chromosomes.

Since chromosomes divide in a very precise manner both during mitosis as well as during meiosis, it is easy to draw a parallelism between chromosomes and genes. Cytoplasm,

however, does not divide in such a precise manner during cell division. Female gamete usually contributes more cytoplasm to the zygote.

Consequently, for characters having cytoplasmic control, differences in reciprocal crosses would be observed. Inheritance in these cases would be mainly of maternal type. If two strains A and B respectively having genotypes AA and BB and cytoplasm a and b are crossed reciprocally, we will get two hybrids AB (a) and AB (b) (cytoplasm is indicated in parentheses). In case of maternal effect, AB (a) and AB (b), despite having same nuclear genotype will differ. AB (a) will resemble strain A or AA (a) and AB (b) will resemble strain B or BB (b). Since such effects are solely produced by cytoplasm of the egg, they are described as maternal effects. However, maternal effects are often produced due to effect of genes through cytoplasm. In other words, properties of cytoplasm depend on nuclear genes. Such cases can be distinguished from those, where extra-chromosomal or cytoplasmic hereditary units are present and function either independently or in collaboration with nuclear genetic system. This is called extra-chromosomal or cytoplasmic or organellar inheritance, and is distinguished from maternal effects.

We know that in chromosomes, DNA is the sole genetic material and is the storehouse of genetic information. Discoveries of presence of DNA in cell organelles found outside the nucleus is a strong evidence to suggest that genetic information does exist in cytoplasm also. It will be seen in this section, that two important and essential organelles i.e. plastids (in plants only) and mitochondria located in cytoplasm carry DNA. These organelles control extra-chromosomal inheritance in many cases through their DNA, which carries genetic information.

The review of literature pertaining to effect of cytoplasm on yield and yield

components in different crop is presented below:

Sorghum

Sorghum hybrids, involving three iso-sterile (A_1 , A_2 and A_4) females and a set of five fertility restorers, were evaluated by Ganga Kishan and Borikar (1989) for yield components in both rainy and winter seasons. In general A_2 cytoplasm had larger grain size and higher yield than traditional milo (A_1) cytoplasm and cytoplasm A_4 had an adverse effect of yield and yield components. Cytoplasmic systems also affected plants height, days to bloom and grain size. Restorers IS 12567C, IS 12662C and SPV 650 had desirable general combining ability effects. The cross ($A_2T \times 398$) $\times$ IS 12662C had the highest mean yield coupled with positive heterosis and specific combining ability effects. Exploitation of A_2 cytoplasm in Sorghum heterosis breeding is suggested.

Evaluation of five pairs of sorghum isonuclear A_1 and A_2 CMS lines in four locations of Tamaulipas, Mexico, viz., Rio Bravo (irrigated), El Tapo (drought), El canelo (drought), Guelatao (drought), during fall summer season of 1992 indicated significant differences between A_1 and A_2 CMS lines for grain yield only in drought conditions (Rodriguez-Herrera *et al.* 1993). However, no significant differences were found between A_1 and A_2 CMS lines for plant height, panicle length and panicle exertion. In a different study using five pairs of sorghum isonuclear A_1 and A_2 CMS lines in Mexico, it was revealed that CMS system did not have any effect on days to flowering (Williams-Alanis and Rodriguez-Herrera, 1992). In another study using 32 isonuclear A_1 and A_2 CMS lines-based hybrids evaluated in ten environments in Northern Mexico during fall winter season of 1990, 1991 and 1993 under irrigated and dry conditions, Williams-Alanis *et al.* (1993) reported absence of significant differences between A_1 and A_2 CMS lines based hybrids for grain yield, plant height,

panicle length and panicle exertion. Sharma *et al.* (1994) and Sharma (2001) reported that the spikelet damage and adult emergence of midges was significantly lower on midge resistant B lines (PM 7061 and PM 7068) than their corresponding A lines, and *vice versa* in the midge susceptible parental lines (296A and ICSA 42). At Patancheru, the maintainer lines (B) flower early by one or two days and has more open panicles than those of their A lines. Further, A₁ cytoplasm was more susceptible to shoot fly than the maintainer line cytoplasm, while the reverse was true for stem borer resistance (Reddy *et al.*, 2003). This finding has significance in developing shoot fly and stem borer resistant hybrids.

Four diversified A₁, A₂, A₃ and A₄ cytoplasmic 272 hybrids of sorghum and their respective parents were subjected to assess the cause and effect relationship of six yield components. Panicle weight showed significant positive association with grain yield with positive direct effect in all four cytoplasmic hybrid groups. However, different relationship existed between yield and other traits when comparing hybrids of different cytotsteriles (Senthil *et al.*, 1997).

Knowledge of maternal and paternal contributions of segregating families to yield components should be useful for generating hybrids with higher yield potential of sorghum. Reciprocal crosses between population steriles and fertile pollinators and two A/B lines differing in seed number and seed weight were used to examine whether maternal effects on seed number and seed weight contribute substantially to grain yield. The sources of experimental material were one large-seeded parent (Wheatland inbred line), one small-seeded parent (46038 inbred line), and a range of male and female parents from the Nebraska Seed Size Population (NSSC5). Measurements from generations P₁ (parent 1 = population), P₂ (parent 2 = inbred line, either 46038 or Wheatland), F₁, F₂, BC₁ (backcross 1) and BC₂ (backcross 2) were obtained in two

experiments, one under field conditions and another under greenhouse conditions. Traits measured were grain yield, yield components and respiration rates through the development of the plant. The genetic analyses included analysis of fixed and random effects with the Multiple Trait Derivative Free Restricted Maximum Likelihood program (MTDFREML). The analysis of random effects used pedigree and inbreeding information. The model included random direct and maternal genetic effects and cytoplasmic effects. ^ Results suggest that maternal effects were important for yield, seed number and seed weight. Cytoplasmic effects were more important for yield and seed number than for seed weight. Respiration rates seem to be controlled primarily by maternal inheritance. Direct genetic effects were more important for yield and seed number than for seed weight. When the model includes maternal and/or cytoplasmic effects, estimates of direct genetic variance were usually reduced (Jose Antonio Hernandez-Alatorre, 2002).

Hybrid sorghum [*Sorghum bicolor* (L.) Moench] seed production relies exclusively on cytoplasmic male sterility (CMS) systems and almost all hybrid sorghum seed is produced using the A₁ CMS system. However, the reliance on a single CMS system increases the vulnerability of the crop to diseases and stresses that may attack that particular CMS system. Alternative CMS systems have been described and even used on a limited basis for hybrid seed production, but a direct comparison of the agronomic effects of different cytoplasms has not been possible because male-sterile lines with a common genetic background (and different cytoplasm) were not available. The recent development of isocyttoplasmic A-lines allows more direct comparison of cytoplasmic effect on agronomic performance. Moran and Rooney (2003) carried out one experiment to determine by means of a set of isocyttoplasmic hybrids if cytoplasm per se influences

agronomic performance. Twelve hybrid genotypes were created in three different cytoplasm (A₁, A₂, and A₃ for a total of 36 hybrids), and they were evaluated for plant height, days to anthesis, and grain yield at Weslaco and College Station, TX, in 1998 and 1999. As expected, significant differences existed among hybrids for plant height, days to anthesis, and grain yield. Cytoplasm type had no effect on plant height and was of minimal practical effect on days to anthesis, but a significant reduction in yield was observed in A₃ cytoplasm hybrids as compared with A₁ and A₂ cytoplasm hybrids. The specific reason for the reduced yield of A₃ hybrids is not known, but seed set data indicated that it was not associated with fertility restoration. The results indicate that hybrids created in A₂ cytoplasm yield comparably to the commonly used A₁ cytoplasm and therefore, the A₂ system will provide a suitable alternative for hybrid seed production should problems be encountered in the A₁ CMS system.

Ramesh *et al.* (2006) studies the Influence of cytoplasmic-nuclear male sterility on agronomic performance of sorghum hybrids. Male-sterility inducing cytoplasm (A₁ and A₂) do have a significant influence on agronomic traits including grain yield, but only in some nuclear genetic backgrounds. The CMS-based A-lines and hybrids were significantly better than those based on their male-fertile counterparts for grain yield in terms of their *gca* effects and mean performance, respectively. However, it is to be noted that these results are based on limited data and need confirmation by multiyear and/or multi-location evaluation.

Kanka Durga *et al.* (2008) studied the influence of cytoplasm on the occurrence of leaf blight [*Exserohilum turcicum* (Pass.)] in sorghum [*Sorghum bicolor* (L.) Moench]. Analysis of the data revealed significant differences among the genotypes and genotype x interaction effects for all the characters under study. However, differences among

cytoplasm's was observed for disease parameters like length and area of the lesion, and agronomic traits like plant height, agronomic desirability, grain yield plant⁻¹ and test weight. For disease related parameters, sterile cytoplasm has contributed significantly to resistance for length and area of the lesion. In case of agronomic traits, fertile cytoplasm has profound dominant effect on agronomic desirability (B-3.4 score/A-3.7 score), grain yield plant⁻¹ (B-33.9 g plant⁻¹ / A-29.8 g plant⁻¹) and test weight (B-2.98 g/A-2.90g) while sterile cytoplasm exerted profound effect on plant height (A-191.2 cm/B-194.1 cm) only.

Rapeseed

McVetty *et al.* (1990) compared the performance of male fertility restored inter-cultivar F₁ hybrids in the *nap* and *pol* cytoplasm to determine the relative effect on performance of these two male sterility inducing cytoplasm. F₁ hybrids (all were 2n = 39 because a common 2n = 40 restorer line was used to produce the F₁ hybrids) in both cytoplasm exhibited superior relative performance compared to the conventional cultivar regent for seed yield, total dry matter and total protein yield. F₁ hybrids in the *pol* cytoplasm performed significantly poorer than F₁ hybrids in the *nap* cytoplasm for seed yield, total dry matter, harvest index, percent oil, total oil yield, and total protein yield. These results suggested a biological cost associated with the presence of the *pol* cytoplasm. The cost of the *pol* cytoplasm, relative to the *nap* cytoplasm, was affected by parental cultivar, but was consistent over a variety of environments.

An experiment was conducted during 2004-05 to study the effect of alien (*Moricandia amensis* (L). DC.) cytoplasm on the expression of heterosis for seed yield and its impact on the productivity of 5 hybrids of Indian mustard (*Brassica juncea* (L.) Czernj. & Coss.). The heterosis declined significantly with replacement of 1 parent (combiner) with

alloplasmic background. The average loss of heterosis which was found to be 6.7% in 'alloplasmic' x 'euplasmic' hybrids rose to 26.9% in 'alloplasmic x alloplasmic' hybrids. 'Pusa Jai Kisan' x 'RLM 198' hybrid manifested maximum heterosis (30.0 - 32.2%) for the seed yield with euplasmic parents but the trend of yield loss with the replacement of alloplasmic parents was similar to that of the other hybrids. The detrimental effect of alien cytoplasm of parents on the productivity of hybrids was also noticed. The average seed yield/plot. 2.52 kg of 'euplasmic x euplasmic' parental hybrids reduced to 2.38 kg with 'alloplasmic' x 'euplasmic' and drastically reduced to 1.96 of 'alloplasmic' x 'alioplasmic' parental hybrids. The average loss of seed yield in hybrids found to be 5.5 % with one alloplasmic parent rose to a considerable high limit of 22.0% with the use of both alloplasmic parents (Katiyar *et al.*, 2007)

Wheat

The nucleo-cytoplasmic interactions of common wheat (*Triticum aestivum* L.) with two of its relatives [*T. macha* L. and *Triticum dicoccoides* (Koern. ex Asch. & Graebner) Aarons.] were studied to determine the effect of the foreign cytoplasm on agronomic traits (Busch and Rauch, 1994). Two high-yielding, semidwarf spring cultivars were crossed reciprocally with one cytoplasm source each of *T. macha* and *T. dicoccoides* to produce four populations with both alloplasmic random lines and euplasmic random lines. Previous reports on these cytoplasm sources were based on the performance of backcross lines in which the recurrent parents were low-yielding, normal height cultivars released in the 1950s and 1960s. Between 30 and 60 random F₄-derived F₆ lines from all populations were grown in five environments in Minnesota from 1986 through 1988. Grain yield, days to head emergence, and plant height were measured in each environment. No significant differences were detected between alloplasmic lines and euplasmic lines for the measured traits in any

population. This was in contrast to an earlier report that *T. macha* cytoplasm increased grain yield in the backcross lines of an old normal height cultivar. Diversity for cytoplasm apparently caused little or no change in normal agronomic performance when using these sources of alien cytoplasm.

Two kinds of wheat hybrids with the same nuclear genotype but different cytoplasm (one with *T. timopheevi* cytoplasm, i.e., A/R, and the other with *T. aestivum* cytoplasm, i.e., B/R) were produced by two 3 × 5 incomplete diallel crosses of 3 A-lines, 3 corresponding B-lines and 5 R-lines, respectively. Experimental results did not show significant differences between the hybrids of A/R and B/R in grain filling characteristics and grain weight. The heterosis of grain weight seems mainly determined by the nuclear genotype. Although the seeds set on most A-lines were shrivelled, such a phenomenon was not found in grains set on F₁. The duration of the lag period (D₁) and the average grain filling rates during the linear period and the mature period (i.e., FR₂ and FR₃) were significantly and positively related to 1000-grain weight. It was in these factors that most hybrids displayed clear mid-parent (MP) heterosis. The amount of grain weight heterosis was not significantly related to MP value. This indicates that the grain weight heterosis of wheat hybrids will not decrease with an increase of the MP value (Zhongqi and Youchun, 1994).

Cotton

Zhu *et al.* (1998) assessed the cytoplasmic effect of cytoplasmic male sterile lines in Upland cotton. Paired A and B lines, cytoplasmic male sterile (CMS) lines and maintainer lines, respectively were crosses with R (restorer) lines to produce A x R, R x B and B x R hybrids, which were evaluated in 1993 and 1996 to predict the performance of three types of CMS cotton lines available in china. A significant difference in yield and yield components was revealed between paired

A x R and B x R hybrids. This difference was greatly influenced by both CMS cytoplasm and the interaction between cytoplasm and nuclear genotypes. It is suggested that there are detrimental effects of CMS cytoplasm on yield and yield components. General combining ability of nuclear-isogenic CMS lines was also affected by this negative effect. The detrimental effect was closely related to an increased number of immature seeds per boll, which might be caused by partial female sterility associated with CMS cytoplasm. The possibilities of developing specific combinations of CMS Upland x Upland restorer hybrids that express enough heterosis for yield to overcome the detrimental effect of the CMS cytoplasm.

For investigating the cytoplasmic effects of the new type CMS-D8 on yield characters and fiber qualities, Wang *et al.*, 2008 designed three types of crosses by A×R, B×R, R×B, and three male-sterile lines (A line), three corresponding maintainer lines (B line) and three restorer line (R line). A lines and R lines were the fifth generations of backcross successively by domestic materials, and the R lines were crossed to the second generations after backcross. The field planting followed by NC II design with two rows and three replications. The field management and pest management followed essentially the practice under the normal agricultural conditions. The examination of field characters included weight and number of boll, lint percentage, seed yield, and lint yield. The fiber qualities were mainly checked on fiber length, strength, uniformity, elongation, and micronaire. The results showed that the greatly significant negative effects were observed on seed yield and lint yield for sterile cytoplasm of D8, the average seed-lint yield declined by 15.3% - 25.6%, lint yield declined 25.0% - 39%; But CMS-D8 had different effects to different yield components, the average decline of bolls weight came to 0.89 -1.00 g, the average decline of lint percentage were

4.59 - 7.08, but had no significantly on number of boll. The fiber length and fiber uniformity were not influenced by sterile cytoplasm of D8, and the fiber strength was improved by 1.0 - 1.1 cN·tex⁻¹, micronaire was reduced to 1.4 - 1.5, fiber elongation was enhanced to 0.4. Different genotypes were influenced differently by sterile cytoplasm of D8.

A total of 31 cytotypes/genotypes with cytoplasmic background from the species *G. arboreum*, *G. anomalum*, *G. harknessii*, *G. barbadense*, *G. tomentosum* and *G. longicalyx* and genotypic background of Bikaneri Narma (BN), SRT-1 and BJR-JK-97-16-4 alongwith the recurrent parents and local check 'H777' were analysed by Ahuja *et al.*, 2002 for their variation in cytoplasmic influence on various traits. Nuclear genotypes and exotic cytoplasm (*G. anomalurri*) significantly affected boll number/plant and mean halo length. For seed cotton yield/plant *G. harknessii* and *G. barbadense* were significantly different from *G. hirsutum* cytoplasm in their influence on boll number/plant. A significant *G. arboreum* cytoplasm difference in comparison to *G. barbadense*, *G. tomentosum* and *G. longicalyx* cytoplasm was observed for boll weight. Per cent bollworm damage on green boll basis of all exotic cytoplasm was significantly different from *G. hirsutum* cytoplasm.

The effects of cytoplasm on productivity and heterosis for seed cotton (*Gossypium hirsutum* L.) yield and its component was studied in 64 hybrids. Four male sterile (A) lines CMS F 505, CMS CSH 2379, CMS LRA 5166 and CMS Jhorar and their corresponding maintainer (B) lines were crossed with eight restorer lines in a line × tester design. The 64 crosses and a standard check, CSHH 198, were grown in a randomized block design with three replications during 2008–09. Analysis of variance revealed significant differences among genotypes. Cytoplasmic effects were estimated by comparing A × R and B × R hybrids combinations. Both positive and

negative cytoplasmic effects were observed for all the characters studied. On the basis of mean of two groups of hybrids, it was revealed that cytoplasm significantly decreased number of bolls/plant, 2.5% span length, maturity coefficient, micronaire value and fibre strength as compared to normal cytoplasm. The estimation of standard heterosis of individual crosses showed that *Gossypium G. harknessii* cytoplasm imparting sterility also influenced heterosis in most of the crosses. Among CMS-based hybrids, CMS Jhorar $\times$ CIR 920 P₁₋₃ (1574 kg/ha), and among conventional hybrids F 505 $\times$ CIR 526 P₂ (1 944 kg/ha) were found to be highest yielding. The range of heterosis varied from -8.8 to 29.9 % in conventional hybrids while heterosis range of CMS cross combinations varied from -5.2 to 5.2 % for seed cotton yield. The combination, CMS F 505 $\times$ CIR 126 P₂₋₁ recorded the highest number of bolls (60.9), and was heterotic by a magnitude of 25.0%, while the highest heterotic effect was observed in F 505 $\times$ CIR 97 P₃₋₄ (37.9%) in conventional crosses. Similar effect of *G. harknessii* cytoplasm has been observed for other characters studied. It is thus the interaction of particular cytoplasm with the nuclear genes that affects performance. It would be more appropriate to test the CMS lines in different combinations rather than converting the female parent of released hybrids into male sterile lines (Tuteja and Banga, 2011).

A study was conducted by Tuteja and Verma (2011) during 2005–06 to find out the effect of alien cytoplasm in ‘alloplasmic $\times$ euplasmic’ hybrids in first experiment, and the effect of alien cytoplasm as well as of alien nuclear genes in the ‘alloplasmic $\times$ euplasmic’ and ‘euplasmic $\times$ euplasmic’ hybrids, respectively, in the second experiment. The hybrids for both the experiments were produced using line $\times$ tester mating system. Yield and contributing traits exhibited superiority of conventional ‘euplasmic $\times$ euplasmic’ hybrids

over cytoplasmic male sterility based ‘alloplasmic $\times$ euplasmic’ hybrids in both the experiments and over the genetic male sterility-based ‘euplasmic $\times$ euplasmic’ hybrids in second experiment. Cytoplasmic male sterility-based ‘alloplasmic $\times$ euplasmic’ hybrids were superior over the genetic male sterility-based ‘euplasmic $\times$ euplasmic’ hybrids in the second experiment for yield and boll weight, however, for fibre quality traits the trend of performance was variable. Alien cytoplasmic and nuclear genes did not exhibit severe deleterious effects for fibre quality related traits, even though a gain was reported in cytoplasmic male sterility based ‘alloplasmic $\times$ euplasmic’ hybrids for 2.5% span length and uniformity ratio over the ‘euplasmic $\times$ euplasmic’ hybrids in first experiment. In the second experiment, cytoplasmic male sterility-based ‘alloplasmic $\times$ euplasmic’ hybrids expressed their superiority over the genetic male sterility-based ‘euplasmic $\times$ euplasmic’ hybrids for most of the fibre quality traits. The average performance of conventional euplasmic $\times$ euplasmic’ hybrids were unambiguously superior over the two types of hybrids for yield and contributing traits and most of the quality traits.

Maize

For decades, little attention has been paid to a potential increase in the yield of maize (*Zea mays* L.) as a result of cytoplasmic male sterility (CMS); however, interest is growing because CMS seed is relatively inexpensive to produce. The present investigations were carried out by Stamp *et al.* 2000, with two hybrids, ‘Corso’ and ‘Silex’, in Switzerland (in 1994 and 1995) and with an open-pollinated cultivar, Suwan 2, in Thailand (1996). These cultivars were tested with non restored T-cytoplasm or with fertile cytoplasm. They were grown with and without nitrogen fertilization at the recommended or at higher plant density; they were grown in Thailand with and without severe preanthesis drought.

CMS increased the grain number per ear of all cultivars; in Corso and Suwan 2 a stable kernel weight resulted in an increase in grain yield as well. Plant density, nitrogen application, and drought did not significantly affect changes in the grain yield as caused by CMS. Choosing hybrids with a positive yield response to CMS is suggested; mixtures with a high percentage of CMS hybrids can then be made with their fertile counterparts.

Male sterility is documented in many plant species. When a plant is male-sterile, an open pollination by a genetically diverse pollinator is possible. Weingartner *et al.*, (2002) investigated the combined effects of non-restored cytoplasmic male sterility (CMS) and xenia (cross-pollination) on the grain yield of seven European flint $\times$ dent single-cross maize (*Zea mays* L.) hybrids. Open pollinated field experiments were conducted in six environments in Switzerland in 1998 and 1999; the design was a split-plot. The effect of CMS on grain yield was statistically significant ($P < 0.05$). Three CMS hybrids in non-restored T-cytoplasm, pollinated by their male-fertile isogenic counterparts, had a higher grain yield (+7.4%) than their male-fertile isogenic counterparts. The higher grain yield was due to a greater number of kernels per square meter (KN). The average increase in grain yield due to xenia was 2.6%. The effects of pollinator hybrids on grain yield, kernel weight (KW), and KN were statistically significant ($P < 0.001$), whereas the pollinator $\times$ environment and pollinator $\times$ CMS hybrid interactions were not significant. Thus, the general pollinator ability (GPA) of the pollinator hybrids differed significantly and consistently. Averaged across the six environments, the three CMS hybrids, pollinated by five non-isogenic hybrids, out yielded their male-fertile, isogenically pollinated counterparts by 2.1, 9.3, and 15.8%, respectively. The best combination of a CMS hybrid and a non-isogenic pollinator hybrid increased grain yield by 21.4% compared with

the male-fertile isogenic counterpart of the CMS hybrid. Therefore, the *plus-hybrid system* (CMS hybrids grown in mixtures with male-fertile non-isogenic pollinator hybrids) combines the grain yield advantages brought about by CMS and xenia.

Kaesler *et al.* (2003) studied the impact of different CMS types on grain yield of dent $\times$ flint hybrids of Maize (*Zea mays* L.). A set of hybrid combinations of Corn Belt dent lines and modern European Flint lines were crossed. In general, CMS had a positive effect on yield of all the tested hybrids in both the years. In the high yielding year 1999 all the tested hybrids with CMS-C cytoplasm yielded higher than the hybrids with CMS-S cytoplasm. In 2000, when the yield were low due to unfavourable weather conditions, all the CMS cytoplasm similarly contributed to an increased yield consistency.

Cytoplasmic male sterility (cms) in maize is used to increase the quality of hybrid seed production and reduce its costs. Xenia is a direct cross fertilisation effect on the grain traits of the female component in the year of crossing. The combined and individual effects of cytoplasmic male sterility and xenia on two ZP maize hybrids were studied by Sofia *et al.*, 2012. This effect is called plus-hybrid effect and can be used for improving grain yield and grain quality in maize. The trials with crosses between two cms hybrids and their fertile counterparts and five unrelated hybrids were set up at one location during three consecutive years. By examining the individual effects of cms and xenia we have observed that the xenia effect on some of the traits differs for sterile and fertile versions of the same hybrid This was observed for 1000 kernel weight, grain number per m² and relative oil and starch kernel content. It seems like there is a kind of interaction between the cytoplasmic male sterility and xenia.

Sunflower

In order to study the influence of different alloplasmic male sterile lines on quantitative characters in sunflower, three alloplasmic male sterile lines of the inbred line 852 were developed. The three different CMS sources used are CMS 852A (*H.petiolaris*), FMS 852A (*H.petiolaris* ssp. *petiolaris*) and IMS 852A (*H.annuus* ssp. *lenticularis*). These three lines were crossed to three restorers Acc. Nos. 1229, 232 and TUB 365 producing 9 hybrids (3 hybrids in three different sources). Similarly inbred line IB24A in two backgrounds FMS IB24A and IMS IB24A were crossed to four restorer lines 1229, 232, Tub 365 and 346 producing another set of 8 hybrids. These 17 hybrids along with their parents were evaluated during rainy season in the field by following randomized complete block design with three replications. Observations were recorded on seven quantitative characters. The different CMS sources did not significantly influence the traits such as plant height, days to maturity, head diameter, per cent seed set, test weight and seed yield per plant. Thus alloplasmic hybrids were uniform suggesting that the new CMS sources can be commercially exploited like classical source with out any negative effect. However, in case of seed oil content the CMS source from *lenticularis* showed superiority over the classical cytoplasm by producing hybrids with significantly higher oil content. Therefore, these new male sterility sources can replace the classical source with added advantage (Patil *et al.*, 2003).

Combining ability studies were made in sunflower using line x tester analysis with seven diverse CMS lines (representing three cytoplasmic sources viz., PET-1, the traditional cytoplasmic source, CMS I from *H. lenticularis* and CMS PEF from *H. petiolaris* ssp.) and eleven testers. Analysis of variance revealed significant differences among the genotypes i.e., parents and hybrids. Nonadditive type of gene action was found

important for expression of all the characters studied. Among the lines, ARM 243B was found to be good general combiner for seed yield, oil content, oil yield, head diameter, number of filled seeds per head and 100 seed weight. R 272-1 and R- 17 were good male parents for seed yield and oil yield. The cross combination PF-400A x P-356R was found to be promising for most of the characters such as seed yield, oil yield, early maturity, head diameter, stem diameter, number of filed seeds per head, seed filling per cent and 100 seed weight. Besides PET-1 source, other sources viz., CMS PEF and CMS I used in the present investigation were equally efficient in expressing their fullest potential of yield and yield contributing characters (Gouri Shankar *et al.*, 2007).

Tobacco

Patel and Pathak (2006) studied depressing effect of cytoplasmic male sterility on cured leaf yield, its components and quality traits in bidi tobacco (*Nicotiana tabacum* L.). Six females consisting of two chewing tobacco varieties, A 145 and GT 6 and two CMS counterparts of each of these varieties having two sources of cytoplasm i.e. from *N. megalosiphon* and *N. undulata*, and 8 diverse pollinators were crossed in a line x tester mating design. The resultant 48 hybrids along with 14 parents were grown in RBD with three replications during *Kharif* 94-95 at B.T.R.S., Anand. The characters studied were cured leaf yield (g/plant), days to flower, number of leaves, plant height (cm), leaf length (cm), leaf breadth (cm), leaf thickness (dry wt. / unit area), stem girth (cm), spangle score, days to maturity, nicotine content (%), reducing sugar content (%), total nitrogen content (%) and potash content (%) . The depressing effect of cytoplasmic male sterility on yield and quality traits was studied by partitioning the mean squares due to hybrids into different components. The analysis of variance revealed that mean squares due to fertile hybrids vs. CMS hybrids were non-significant for all the

characters except days to flower, stem girth and nicotine content, indicating that there is no difference between fertile and CMS hybrids with respect to all the characters studied except days to flower, stem girth and nicotine content. The mean squares due to CMS hybrids (m) vs. CMS hybrids (u) revealed non-significant differences for all the characters except plant height, days to maturity, nicotine content and reducing sugar indicating that hybrids developed from both the cytoplasmic male sterile sources are equally good for yield and other traits except some yield components and quality traits. The study suggested that CMS lines having cytoplasmic sources from *N. megalosiphon* and *N. undulata* can safely and profitably be used in heterosis breeding programme for the improvement of yield and its components in bidi tobacco. However, important quality traits viz., nicotine content and reducing sugar should closely be monitored while considering a hybrid for commercial cultivation. The female lines from CMS *undulata* source can be of immense value because of their protruding stigma, which will help in producing more quantity of hybrid seed in shorter time.

Pearl Millet

Cytoplasmic male sterility (CMS) is considered an efficient genetic tool in pearl millet hybrid breeding. Of the several CMS sources available in pearl millet, A₁ is the only CMS widely exploited to produce commercial hybrids in India. To explore the possibility of using alternate CMS sources, Chandra-Shekara *et al.* (2007) studied the cytoplasmic effects of different CMS sources on agronomic characters in pearl millet. Five CMS (A) lines representing A₁, A₂, A₃, A₄ and A₅ cytoplasm, their respective maintainer (B) lines and eight restorer (R) lines were used to generate 40 A × R and B × R experimental crosses. The experimental material was evaluated at two different locations in India. Analysis of combining ability and heterosis revealed that A₄ and A₅ cytoplasm had desirable effects

for earliness. The A₅ CMS was found to be particularly promising, as compared to other CMS sources for improving grain yield. The study also indicated that the cytoplasmic effects on general combining ability (GCA) for various agronomic characters were largely non-significant. However, cytoplasmic effects on specific combining ability and heterosis were found to be modulated by cytoplasmic-nuclear interactions and influenced by the environmental conditions. The study also demonstrated the advantage of utilizing diverse male-sterile and restorer combinations in maximizing the productivity as well as for genetic and cytoplasmic diversification of hybrids in pearl millet.

Isonuclear A-lines with A₁, A₄ and A₅ cytoplasm in five diverse genetic backgrounds (ICMA 88004, ICMA 89111, ICMA 94555, ICMA 96111 and ICMA 96666) crossed with 19 cytoplasm-specific R-lines generated 285 F₁ hybrids, which were evaluated for male fertility/ sterility in two contrasting seasons (post rainy season and rainy season) of 2009 at ICRISAT, Patancheru, India. Fertility restoration of hybrids with the A₄ and A₅ cytoplasm was neither affected by the genetic backgrounds nor by the environments as 94 hybrids in each cytoplasmic background was fertile during the post rainy season, while all 95 hybrids were fertile in the rainy season. In case of hybrids with the A₁ cytoplasm, genetic background of the male-sterile lines as well as the environments had strong effect on fertility restoration of hybrids. The largest proportion of hybrids with this cytoplasm (14%) were sterile during the post rainy season, indicating that evaluation of hybrids during the post rainy season may be more efficient to identify those with stable fertility restoration across the environments (Gupta *et al.*, 2010).

The effect of cytoplasm on productivity and combining ability for grain yield and its contributing traits was studied in 144 hybrids of pearl millet by Kumar and Sagar (2010). Six male sterile (A) lines 81A

and HMS 8A (A₁), Pb313A (A₂), Pb402A (A₃), 81A₄, 81A₅ representing five different cytoplasm systems and their corresponding maintainer (B) lines were crossed with 12 restorer (R) lines in a line x tester design. The 24 parents (A + B and R) and 144 crosses were grown separately in contiguous block in randomized block design with two replications in six environments, three each (E₁, E₂, E₃) and (E₄, E₅, E₆) during 2000 and 2001, respectively. Analysis of variance revealed significant differences among genotypes, parents, lines (A, B), testers, hybrids (A x R, B x R). The differences due to A vs. B and A x R vs. B x R crosses were highly significant for grain yield/plant (g), harvest index (%) and growth rate (g/plant/day). Cytoplasmic effects were estimated by comparing A x R and B x R hybrids combination. Both positive and negative cytoplasmic effects were observed for all the four characters studied. The (A x R vs. B x R) x E component of variance exhibited significance for all the four characters. The effects were modified by environment. These were more pronounced for grain yield, 500-grain weight and harvest index, and positive cytoplasmic effects exceeded than the negative ones. For growth rate negative cytoplasmic effects were preponderant and significant only in one environment which is due to cytoplasm and nuclear genome interaction. Effect of cytoplasm was more or less equally pronounced on general combining ability effects of parents and specific combining ability of crosses. Array mean performance of 81A cytoplasmic iso-hybrids indicated that all the three cytoplasm have same potential, therefore, any of these cytoplasm can be used in hybrid breeding.

Pigeonpea

Dalvi *et al.* (2008) studied fertility restoration in three cytoplasmic-nuclear male-sterile (CMS) lines (ICPA 2067, ICPA 2052 and ICPA 2039), each derived from *Cajanus sericeus* (A₁ cytoplasm), *Cajanus scarabaeoides* (A₂ cytoplasm) and *Cajanus*

cajanifolius (A₄ cytoplasm), respectively. These lines were crossed to 7 popular pigeonpea varieties in line x tester mating scheme. Twenty one F₁ hybrid combinations were planted in un-replicated 3 row plots in 3 environments. The information generated from this experiment showed that ICPL 129-3 can be used to develop hybrids on CMS lines derived from A₁ cytoplasm, whereas cultivars BSMR 175, ICPL 129-3, and Nirmal 2 can be used for the development of new diverse CMS lines with A₂ cytoplasm. Because ICPL 129-3 maintained male sterility in A₄ cytoplasm, it could be used for development of a new A line. Cultivars BDN 2, BWR 23, BSMR 736, and BSMR 853 showed more or less similar reaction for fertility restoration across the 3 CMS lines. There were differences among testers for fertility restoration of different cytoplasm and the same cytoplasm showed different fertility restoration behavior with different testers. The partial fertility restoration observed in some hybrid combinations could be attributed to genetic impurities in the male parents, which could be due to natural out crossing and difficulties in the maintenance of genetic stocks under natural pollination. Such lines, however, can easily be purified by selfing and single plant selection for 2–3 generations.

Patel *et al.* (2013) studied the effect of A₂ cytoplasm of *Cajanus scarabaeoides* on yield and yield components in pigeonpea [*Cajanus cajan* (L.) Millsp.] and reported that A₂ cytoplasm has positive impact on seed yield, harvest index and early maturity in A₂ cytoplasm based hybrids than that developed from their fertile counterpart (B) lines having native cytoplasm. The impact was evident in other characters too but this impact was not in a predictable direction and varied with genotypes and character. Though the superiority of A₂ cytoplasm was evident in developing better hybrids for harvest index, yet there was no clear cut pattern of superiority or inferiority of A₂ cytoplasm in yielding

better per se hybrids for other traits as compared to native cytoplasm in B lines.

Rice

Thirty-two aF₁ and thirty-two bF₁ rice hybrids were evaluated to investigate the effect of wild abortive and ARC male sterile cytoplasm on grain yield and seven grain quality components. The study indicated that in general, sterile cytoplasm exerted more negative effects on head rice recovery and gel consistency, while positive effects were predominant on kernel length and length/breadth ratio. Among four CMS lines of two sources, IR62829A and IR67683A of wild abortive source were found to be promising as they showed pronounced positive effects on grain quality traits. Eleven aF₁ hybrids consistently showed significant superiority for grain yield when compared to their respective bF₁ hybrids. Although most of the hybrids possessed desirable grain qualities, six aF₁ hybrids viz., IR62829A × IR64, IR62829A × IR46, IR62829A × WGL3962, IR67683A × Vajram, IR67683A × Samba Mahsuri and IR67683A × Vijetha showed consistent superiority for head rice recovery than their respective bF₁ hybrids. The positive cytoplasmic effect on head rice recovery resulted due to the negative cytoplasmic effect on kernel length. All the rice hybrids resulted from IR58025A (with maximum grain length and slenderness), were found to be inferior to bF₁ hybrids for head rice recovery indicating the need for selection of specific maternal parent in hybrid production to minimize the negative effects on grain quality (Rani, 2008).

To detect cytoplasmic effects in rice, Dayun *et al.* (2011) introgressed the nuclear genomes of three *indica* rice cultivars Guichao 2, Jiangchengkugu, and Dianrui 449 into the cytoplasm of six *indica* rice cultivars Dijiaowujian, Shenglixian, Zhuzhan, Nantehao, Aizizhan, and Peta. These 18 nuclear substitution lines were evaluated during the winter season of 2005 in Sanya, Hainan, China, and during the summer season

of 2006 in Kunming, Yunnan, China. The effects of 6 cytoplasm sources, 3 nucleus sources, 2 locations and their interactions were estimated for plant height, panicle length, panicle number per plant, spikelet number per panicle, grain weight, filled grain ratio, and yield per plot. For five of the seven traits, analysis of variance showed that there were no significant cytoplasmic effects or interactions involving cytoplasmic effects. The effect of cytoplasm on 1000-grain weight was highly significant. Mean 1000-grain weight over the two locations in four of the six cytoplasm clusters close to the overall mean, whereas plants with Nantehao cytoplasm had a high, and those with Peta cytoplasm a low mean grain weight. There was a highly significant three way interaction affecting filled-grain ratio. At Sanya, cytoplasm varied in very narrow ranges within nuclear backgrounds. Strong cytoplasmic effects were observed only at Kunming and in only two of the three nuclear backgrounds; in the Jianchenkugu nuclear background, there was no evidence of strong cytoplasmic effects at either location. In the Dianrui 449 and Guichao 2 nuclear background evaluated at Kunming, filled-grain ratios of the six cytoplasm showed striking rank shifts. The cytoplasm source had a significant effect on grain weight across the two experimental locations. There was also a significant cytoplasmic effect on filled-grain ratio, but only in two of three nuclear background and at one of the two locations. The results extend our previous findings with japonica rice, suggesting that the selection of appropriate cytoplasmic germplasm is broadly important in rice breeding, and that cytoplasmic effects on some traits, such as filled-grain ratio, cannot be generalized; effects should be evaluated in the nuclear backgrounds of interest and at multiple locations.

REFERENCES

Ahuja S.L., Tuteja O.P. and Banerjee S.K. (2002). Effect of exotic cytoplasm on

- yield, its components, bollworm incidence and jassid grade in cotton (*G. hirsutum* L.). *Indian J. Agric. Res.*, **36** (3): 162-166.
- Braun, C. J., Siedow, J. N., Williams, M. E. and Leving III, C. S. (1989): Mutations in the maize mitochondrial T-urf13 gene eliminate sensitivity to a fungal pathotoxin. *Proc. Natl. Acad. Sci.* **86**: 4435-4439.
- Bush, R. H. and Rauch, T. L. (1994). Alien cytoplasmic effects on agronomic performance of two high yielding semidwarf spring wheat cultivars. *Crop Sci.*, **34** (2): 389-391.
- Chandra-Shekara, A.C., Prasanna, B.M., Singh, B.B., Unnikrishnan, K.V. and Seetharam, A. (2007). Effect of cytoplasm and cytoplasm-nuclear interaction on combining ability and heterosis for agronomic traits in pearl millet [*Pennisetum glaucum* (L.) Br. R.]. *Euphytica*, **153** (1-2): 15-26.
- Dalvi, V. A., Sexena, K.B. and Madrap, I. A. (2008). Fertility restoration in cytoplasmic-nuclear male sterile lines derived from 3 wild relatives of pigeonpea, *J. Hered.*, **99** (6): 671-673.
- Dayun, T., Peng, X., Jiawu, Z., Xianneng, D., Jing, L., Wei, D., Jiangyi, Y., Guifeng, Y., Qiong, L. and Fengyi, H. (2011). Cytoplasm affects grain weight and filled-grain ratio in *Indica* rice. *BMC Genet.*, **12**:53-58.
- Ganga Kishan, A. and Borikar, S. T. (1989). Line × Tester Analysis Involving Diverse Cytoplasmic Systems in Sorghum. *Plant Breed.*, **102**(2): 153-157.
- Gouri Shankar, V., Ganesh, M., Ranganatha, A.R.G., Suman, A. and Sridhar, V. (2007). Combining ability studies in diverse cms sources in sunflower (*Helianthus annuus* L.). *Indian J. Agric. Res.*, **41** (3): 171-176.
- Gupta, S. K., Rai, K. N. Kumar, M. S. (2010). Effect of genetic background on fertility restoration of pearl millet hybrids based on three diverse cytoplasmic-nuclear male-sterility systems. *Journal of SAT Agricultural Research*, **8**: 4pp.
- Jose Antonio Hernandez-Alatorre (2002) Maternal and cytoplasmic effects on components of sorghum grain yield. *ETD collection for University of Nebraska - Lincoln*. Paper AAI3064577.
<http://digitalcommons.unl.edu/dissertations/AAI3064577>
- Kaesler, O., Weingartner, U., Camp, K. H., Chowchong, S. and Stamp, P. (2003). Impact of different cms types on grain yield of dent x flint hybrids of maize (*Zea mays* L.). *Maydica*, **48**: 15-20.
- Kanka Durga, K., Reddy, B. V. S., Reddy, M. S. S. and Ganesh, M. (2008). Influence of cytoplasm on the occurrence of leaf blight [*Exserohilum turcicum* (Pass.)] in sorghum [*Sorghum bicolor* (L.) Moench.]. *Indian J. Agril. Res.*, **42**(2): 97-101.
- Katiyar, R.,K., Chamola, R. and Yadav, Mamata (2007). Effect of alien cytoplasm on expression of heterosis and productivity of Indian mustard (*Brassica juncea*) hybrids. *India. J. Agric., Sci.*, **77** (3): 158-161.
- Kumar, R. and Sagar, P. (2010). Effect of cytoplasm on combining ability and yield attributes in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Indian J. Genet.*, **70**(3): 247-256.
- Lossel, A., Adler, N., Horn, Frel, U. and Wenzel, G. (1999): Chondriome Type Characterization of Potato: Mt a, b, g, d, e and Novel Plastid-Mitochondrial Configurations. *Theor. Appl. Genet.*, **99**: 1-10.
- McVetty, P. B. E., Edie, S. A. and Scarth, R. (1990). Comparison of the effect of

- nap* and *pol* cytoplasm on the performance of intercultivar summer oilseed rape hybrids. *Canadian J. Plant Sci.*, **70**: 117-126.
- Moran, J. L. and Rooney, W. L. (2003). Effect of cytoplasm on the agronomic performance of grain sorghum hybrids. *Crop Sci.*, **43**: 777-781.
- Patel J. B. and Pathak H. C. (2006). Depressing effect of cytoplasmic male sterility on cured leaf yield, its components and quality traits in bidi tobacco (*Nicotiana tabacum* L.). *International J. Biosci. Reporter*, **4**(2): 267 – 270.
- Patel, J. B., Patil Ramanand, Acharya, S. and Jadhav, S. S. (2013). Effect of A2 cytoplasm of *Cajanus scarabaeoides* on yield and yield components in pigeonpea [*Cajanus cajan* (L.) Millsp.]. *AGRES- An International e-Journal*. **2**(1): 38-43.
- Patil, S. A., Gafoor, A. and Ravikumar, R. L. (2003). Impact of cytoplasmic male sterile sources on seed yield and yield components in sunflower. *Helia*, **26**(38): 67-72.
- Ramesh, S., Reddy, B. V. S., Reddy, P. S. and Ramaiah, B. (2006). Influence of cytoplasmic-nuclear male sterility on agronomic performance of sorghum hybrids. *International Sorghum and Millets Newsletter*, **47**: 21-25.
- Rani, C. V. D. (2008). Remove from marked records effects of male sterile cytoplasm on grain yield and grain quality characters of rice hybrids. *Current Biotica*, **2**(4): 374-386.
- Reddy, B. V. S., Rai, K. N., Sharma, N. P., Kumar, I. and Saxena, K. B. (2003). Cytoplasmic-nuclear male sterility: Origin, evaluation, and utilization in hybrid development. In *Plant Breeding: Mendelian to Molecular Approaches* (Jain HK and Kharkwal MC, eds.). New Delhi, India: Narosa Publ. House Pvt. Ltd.
- Rodriguez-Herrera R., Torres-Montalvo, H. and Williams-Alanis, W. (1993). Comparative performance of maintainer and male-sterile sorghum iso-genic lines in A₁ and A₂ cytoplasm. *Sorghum Newsl.*, **34**:50.
- Senthil, N. Ramasamy, P. and Khan, A. F. Z. (1997). Effect of diversified cytoplasm on the interrelationship between yield components in sorghum. *Crop Improv.*, **24** (2): 263-266.
- Sharma, H. C. (2001). Cytoplasmic male-sterility and source of pollen influence the expression of resistance to sorghum midge *Stenodiplosis sorghicola*. *Euphytica*, **122**:391-395.
- Sharma, H. C., Vidyasagar, P., Abraham, C. V. and Nwanze, K. F. (1994). Effect of cytoplasmic male sterility in sorghum on host plant interaction with sorghum midge, *Contarinia sorghicola*. *Euphytica*, **74**:35-39.
- Sofija, B., Jelena, V., Slaven, P., Zoran, C., Milan, S., Nikola, G. and Milos, C. (2012). Different xenis effect on sterile and fertile version of hybrids in maize. Paper presented in *Third International Scientific Symposium "Agrosym Jahorina 2012"*. 10.7251/AGSY1203285B.
- Stamp, P., Chowchong, S., Menzi, M., Weingartner, U. and Kaeser, O. (2000). Increase in the yield of cytoplasmic male sterile maize revisited. *Crop Sci.*, **40** (6): 1586-1587.
- Topping, J. F. and Leaver, C. J. (1990): Mitochondrial gene expression during wheat leaf development. *Planta*, **182**: 399-407
- Tuteja, O. P. and Banga, Manju (2011). Effects of cytoplasm on heterosis for agronomic traits in upland cotton (*Gossypium hirsutum*). *The Indian J. Agric. Sci.*, **81** (11): 1001-1007.

-
- Tuteja, O. P. and Verma, S. K. (2011). Effect of alien cytoplasmic and nuclear genes on seed cotton yield and fibre quality traits in cotton (*Gossypium hirsutum*). *Indian J. Agric. Sci.*, **81**(4): 296-304.
- Wang, A. N. G., Hu, Z., Guo, X., Gao, M., Nie, Y. and Zhang, X. (2008). Research for cytoplasm effects of new type CMS-D8 on cotton. *Crop Sci.*, **20** (2): 83-87.
- Weingartner, U., Kaeser, O., Long, M. and Stamp, P. (2002). Combining Cytoplasmic Male Sterility and Xenia Increases Grain Yield of Maize Hybrids. *Crop Sci.*, **42** (6): 1848-1856.
- Williams-Alanis, H. and Rodriguez-Herrera, R. (1992). Cytoplasmic-genic male-sterility effect in flowering of sorghum iso-genic lines. *Sorghum Newsl.*, **33**:17.
- Williams-Alanis, H., Rodriguez-Herrera, R., Aguirre-Rodriguez, J. and Torres-Montalvo, H. (1993). Comparative performance of iso-genic sorghum hybrids in A₁ and A₂ cytoplasm. II. Yield and agronomic characteristics. *Sorghum Newsl.*, **34**:51.
- Zhongqi, L. and Youchun, L. (1994). Heterosis of grain weight in wheat hybrids with *Triticum timopheevi* cytoplasm. *Euphytica*, **75** (3): 189-193.
- Zhu, X. F., Wang, X. D., Sun, J., Ahang, T. Z. and Pan, J. J. (1998). Assessment of cytoplasmic effects of cytoplasmic male sterile lines in upland cotton. *Plant Breed.*, **117**: 549-552.