# MATERNAL AND CYTOPLASMIC EFFECTS ON COMPONENTS OF SORGHUM GRAIN YIELD

by

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GRADUATE COLLEGE
UNIVERSITY OF NEBRASKA

# MATERNAL AND CYTOPLASMIC EFFECTS ON COMPONENTS OF SORGHUM GRAIN YIELD

Jose Antonio Hernandez-Alatorre, Ph.D.

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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 ($NSSC_5$). 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.

**In Memory of my Mother and my Father:**

**Maria Antonia Alatorre de Hernandez**

**and**

**Jose Isabel Hernandez Torres**

**This dissertation is dedicated to my wife Laura Imelda, my daughters Maria Imelda and Monica and my son Jose Antonio. This is dedicated also for my brothers and sisters: Gerardo, Jorge, Luis, Mario, Carmela and Ana Isabel.**

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# INTRODUCTION

Commercial sorghum (*Sorghum bicolor* L.) hybrid development is done almost solely via standard pedigree line development methodology with very little input from commercial population development. Furthermore there are few public institutions where random mating populations play a significant role in improved line and /or hybrid development. Given the comparatively large number of recombinations possible within random mating populations compared to line breeding programs alone, careful use of selectively synthesized populations would seem to offer utility in improving grain yields via manipulation of the main yield components seed weight and seed number.

The primary abiotic adaptation of interest for most sorghum production environments are high temperature and water stress tolerances. Therefore, a tan plant color (food grain type) population NP39R was developed (using genetic male sterility $ms_3$) cooperatively in Western Kansas (hot, dry environments) with Kansas State University scientists. Selection pressure was set up to screen for a high, comparatively stable seed number that resulted in high seed number population genotypes with relatively small seeds, good water/high temperature stress tolerances and high yield potentials.

Simultaneous to development of NP39R, testing of hybrids of other stress tolerant lines in hybrid combinations revealed that the highest yielding hybrids consistently had larger seeds under both good and stress conditions which is contrary to the current general belief that when seed weight goes up yield goes

down and vice versa. Therefore, it seemed prudent to put genes for larger seed weight into the stress resistant NP39R population, which gave rise to the $NSSC_5$ (Nebraska Seed Size Population), cycle 5 which was used in the current study.

Further, it seemed that optimum utilization of $NSSC_5$ type of populations might be more likely to be realized through identifying potentially favorable contributions of maternal and paternal sources from segregating genotypes selected within the population which is quite diverse in terms of seed weight and seed number yield components. Such identification of maternal and paternal contributions from population genotypes to both seed weight and seed number components to hybrid yields is the overall objective of this research. This would permit the identification of which lines (or segregating population genotypes) should be used as female parents and which lines (or segregating population genotypes) would serve best as pollinators in hybrid breeding programs.

The specific contributions of parents to progeny have been studied since the beginning of plant breeding. Maternal effects are mainly of two types: genetic (effect of the mother in addition to the genetic effects of the sample one-half of her genes transmitted to her offspring (Van Vleck, 1993), and cytoplasmic (cytoplasmic genetic maternal effects are derived from the fact that organelles such as plastids and mitochondria can be directly tranferred from the maternal plant to the offspring during ovule formation and development, and this transmission is independent of nuclear genes (Roach and Wulff, 1987). Paternal effects can be xenia effects of pollen grains on the endosperm of the mother plant plus normal genetic effects on virtually all yield dependent metabolic and

developmental processes. Maternal effects have been traditionally estimated by comparing the F1 hybrids from reciprocal crosses, while cytoplasmic effects have been estimated by comparing the F2 populations derived from reciprocal F1's or from the backcrosses using the reciprocals F1's as seed parents (Mosjidis and Yermanos, 1984).

Research on maternal and paternal contributions usually has been done by using inbred lines as parents with very little study of open pollinated varieties or segregating genotypes from random mating populations. When inbred lines are used as parents, the main objective is the study of their means, which can be done with analysis of diallel crosses (Cockerham and Weir, 1977) or with generation means analysis (Barnes, 1968; Mosjidis et al. 1989). When selections from open pollinated varieties or randomly mating populations are utilized as parents, the objective is to estimate not only means but also variances and covariances. These estimates can be obtained by using composite effects models (Lynch and Walsh, 1998) or mixed model equations (Henderson, 1975).

Mixed model equations have been used for estimating maternal effects in animal breeding research (e.g., Van Vleck, 1993) and could be adapted for estimating genetic effects in plants when variation is expected from segregating populations.

# CHAPTER 1

## MATERNAL AND CYTOPLASMIC EFFECTS ON COMPONENTS OF SORGHUM GRAIN YIELD

# ABSTRACT

The identification of lines and families of grain sorghum (*Sorghum bicolor* L.) for increasing seed size and seed number components of yield, hopefully simultaneously, from randomly mated populations featuring wide ranges of seed weights and seed numbers could serve as an effective breeding method. Progress in developing more favorable gene combinations for increasing yields to complement the usual inbred line crossing method being used commercially might be improved through identification of maternal and paternal source effects of various randomly mated population derivatives.

Information regarding the maternal and paternal contributions of segregating families may be useful for generating hybrids with higher yield potential. 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 may contribute to grain yield. The sources of experimental material were one large-seeded parent (Wheatland inbred line), one small-seeded parent (46038 inbred line) (including the A and B versions of each inbred line), and a range of male and female parents from the Nebraska seed size population ($NSSC_5$). Measurements from generations P1 (parent 1 = population), P2 (parent 2 = inbred line), F1, F2, BC1 (backcross 1) and BC2 (backcross 2) direct and reciprocals were obtained in two experiments, one under field conditions and another carried out under greenhouse conditions. Traits measured were 500-

grain weight, grain number per plot and grain yield. 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.

The results suggest that maternal effects were important for yield, seed number and seed weight. Reciprocal effects were different for most of the F1 progenies. Significant variation due to maternal effects was found. Cytoplasmic effects were more important for yield and seed number than for seed weight. Persistent differences between reciprocal crosses were observed for most of the filial generations. Most of the variance due to cytoplasmic effects originated from cytoplasmic sources from the $NSSC_5$ population and the 46038 inbred line. Respiration rates seem to be maternally inherited.

Direct (additive) genetic effects were more important for yield and seed number traits than for seed weight. Direct genetic effects usually were associated with low estimates of genetic variance and heritability when included in the model together with maternal and/or cytoplasmic effects.

# LITERATURE REVIEW

Maternal effects can be detected and analyzed easily and unambiguously for inbred lines. Inbred lines are not, however, needed for this purpose in all circumstances. With hermaphroditic species, each individual can be used both as a maternal and paternal parent so that maternal effects can be detected by making crosses reciprocally between pairs of individuals irrespective of whether they are homozygous or heterozygous (Mather and Jinks, 1971).

Maternal effects have been studied in different crops for various traits. Singh and Hadley (1972) reported results from experiments designed to determine the effects of cytoplasm and genotype of the maternal parent on protein content in soybean (*Glycine max* L.) seeds. Maternal effects were estimated by comparing means of F1 seeds with those of selfed seeds on the same female parental plants. Cytoplasmic effects were detected by comparing means of F2 seed borne on F1 plants from reciprocal crosses. Their main results indicated that the mean of F1 seeds did not differ from that of selfed seeds produced in the same plant which suggests strong maternal effects.

In sorghum, (*Sorghum bicolor* L.) Eastin et al. (1998), from physiologically based screening, found that the "Wheatland" x 17473 hybrid grain sorghum mean of 7, 367 kg $ha^{-1}$ exceeded the Tx 3042 hybrid mean of 6, 476 kg $ha^{-1}$ by 14%, even though the Tx 3042 hybrids have 23, 200 seeds $m^{-2}$ compared with the 19, 300 seed $m^{-2}$ for the Wheatland hybrids (11% superiority for Tx 3042 hybrids). The yield of Wheatland hybrid was superior because the seeds were

26% larger (3.53 vs. 2.81 g 100 seeds$^{-1}$). With pollinators being common and females being different, seed size was clearly a female effect in their experiment.

Diallel-crossing methodology has been used extensively in the past for estimating maternal effects. More recently generation means analysis has been used for estimating maternal effects

Corey et al. (1976) used a diallel model to study maternal and cytoplasmic effects on three seedling characters of F1 hybrids of *Arabidopsis thaliana* (L.) Heyuh'. Evidently, they used inbred lines as parents. Effects in their model included mean, nuclear genetic effects of the parents, nuclear genetic interaction effect of the parents, effect of maternal cytoplasm, interaction effects of the cytoplasm and the nuclear genetic contributions of the parents. The model was similar to that presented by Yates (1947) and Cockerham (1963).

Barnes (1968) reported results from an analysis of the genetic system controlling number of progeny of *Drosophila melanogaster*. The parental, F1, F2 and backcross generations, including all reciprocals, of two inbred lines were raised in each of three fully randomized blocks. The mean, additive and dominance effects were estimated by weighted least squares using as weights the reciprocals of the variances of the generation means. Maternal effects were estimated by an additional parameter [f]. In the comparison between the observed and expected generation means, the $\chi^2$ test with degrees of freedom equal the number of generation means minus the number of parameters estimated showed that the model adequately summarizes the data. The

important components of the model were dominance in the direction of higher progeny number, and maternal effects associated with the F1.

In a similar way, Tyson (1973) made crosses between four flax (*Linum usitatissimum)* genotypes to generate F1, F2 and backcross generations. Unequal sub-class numbers were handled by an appropriate least-squares procedure, and comparisons were made among the estimated means of progenies. No differences between reciprocal F1 hybrids were detected.

In animal breeding maternal effects have been estimated by using a variety of programs and the MTDFREML set of programs (Boldman et al. 1993). The MTDFREML program has been used for the analysis of genotype x environment interactions in experiments with plants (Rodriguez-Herrera, 1992 and Coutiño-Estrada, 1998) but could also be used in analyses of genetic effects.

Regarding paternal effects Leng (1949), in his classical work on the direct effect of the pollen parent on kernel size in dent corn, found that when used as pollen parents certain inbred lines were found to differ significantly in their effects on the weight of F1 kernel. Pollen effects from the $R_4$ inbred line reduced weight as much as 20%, as compared with effects of pollen from a number of other inbred lines. This depressing effect on kernel weight was observed in all crosses in which $R_4$ was the pollen parent.

Burton et al. (1980) conducted research to study the pollen parent effect on several chemical components in pearl millet (*Pennisetum americanum L.*) grain. They found that the female effect was greater than the male effect. However, open-pollinated seed was significantly superior to self-pollinated seed