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Response to Four Cycles of Mass Selection for Prolificacy at Low and High Population Densities in Small Ear Waxy Corn

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Abstract: Four cycles of modified mass selection for prolificacy in Tein Luang Nong Bua population of small ear waxy corn at low and high population densities (62,500 and 125,000 plants ha^{-1}) were completed in 2006. The initial population and eight improved populations were evaluated at two planting densities. The objectives were to evaluate the responses of these populations to population density and to estimate selection responses of improved populations for agronomic characters and ear traits. Number of ears per plant increased from 1.75 at cycle 0 to 1.84 at cycle 4 with average rates of gain per cycle of 0.03 ears per plants at low planting density. At high planting density, the average ears per plant increased from 1.75 at cycle 0 to 1.99 at cycles 4 with average rates of gain per cycle of 0.05 ears per plants. Mass selection at high population density resulted in higher response than the one at low population density (increased by 0.07 vs. 0.05 and 0.03 vs. 0.02 ears per plant cycle^{-1} for low and high planting densities, respectively). Correlated response to selection was observed in both low and high planting densities for plant high (2.9** and 2.8**), ear height (b = 2.3 * and 2.5*), days to tasseling (b = 0.48* and 0.53*) and days to silking (0.53* and 0.41*). It could be concluded that mass selection under both high and low plant densities could increase number of ears and selection under high plant density was more effective than under low plant density.

Key words: Correlated response, ear number, marketable ears, modified mass selection, *Zea mays* L. var. *ceritina*

INTRODUCTION

Small ear waxy corn (*Zea mays* L. var. *ceritina*) has been grown widely as a cash crop for sticky taste green corn for centuries in countries in Eastern Asia including China, Myanmar, Laos, Vietnam, Cambodia, Korea and Thailand. It is believed to originate thought mutation from normal maize in Southwest China and it is consumed as special food or staple food by people in these regions (Tian *et al*., 2009). The landraces presently cultivated in Thailand are mostly open-pollinated and they differ in yield, ear size, ear shape, kernel color and eating quality. This opens up new possibilities for genetic improvement of the crop.

Mass selection for prolificacy has been used successfully for the improvement of yield and associated characters in field corn (De Leon and Coors, 2002) and sweet corn (Ali and Saleh, 2003). However, breeding of small ear waxy corn is lacking behind compared to field corn and sweet corn because breeding efforts to improve this type of corn are more recent and the information on genetic improvement is very scarce.

De Leon and Coors (2002) demonstrated that mass selection was effective for increasing the number of active ear shoots in the Golden Glow maize population. Ali and Saleh (2003) found some increase in yield of two sweet corn populations after two cycles of mass selection and they suggested selection of more cycles for more pronounced results.

There has been considerable evidence that prolificacy is associated with higher yields in field maize (Uhr and Goodman, 1995; Maita and Coors, 1996; Jampatong *et al*., 2000). Onenanyoli and Fasoulas (1989) reported that selection based on grain yield in honeycomb arrangement also increase prolificacy. Although, prolific hybrids yielded better than non-prolific hybrid type, however, Varga *et al*. (2004) found that prolificacy *per se* did not have any important effect on hybrid performance when grown under reduced input compared to high-input cropping system.

As small ear waxy corn landraces have high variations in number of ear per plant (1-3 ears), yield improvement of this type of corn through selection for prolificacy may be possible. However, there is very limited

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information on the relationship between ear number and yield in this type of corn and the selection response for prolificacy at different population densities for small ear waxy corn is also limited in the literature. The objectives of this study were to investigate responses of corn populations to population density and to evaluate selection response to four cycles of modified mass selection for prolificacy in a small ear local waxy corn Tein Luang Nong Bua selected at high and low plant population densities.

MATERIALS AND METHODS

Population development and selection procedures: In 2005, mass selection experiment for prolificacy was initiated in a local variety of small ear waxy corn Tein Luang Nong Bua at the faculty of Agriculture, Khon Kaen University. This population was selected because of its good eating quality and tendency to prolificacy, producing 1-4 ears per plant and its popularity among growers in Khon Kaen Province in the Northeast, Thailand. However, it is not resistant to downy mildew and other foliar diseases. It also has poor root systems and slender stalks. Selection was carried out separately at low and high densities (62,500 and 125,000 plants ha^{-1}, respectively). Plants were grown at inter-row spacing of 80 cm and intra-row spacing of 20 cm. This spacing was remained constant for both high and low densities, but number of plants per hill varied between one plant and two plants for low and high densities, respectively. The modified mass selection for prolificacy was carried out for each cycle. Prior to silk emergence, the first and second ear shoots of healthy plants with good root system and stalk strength, showing early development of multiple ear shoots and good silk synchronization were covered with ear bags and tassels of each selected plants were also covered with tassel bags. At two days after silking, bulked pollens from selected plants were used to pollinate all ears of selected plants. At harvest, the first ears (upper ears) of the plants producing at least two ears per plant were selected. However, pollen donors inevitably included the plants with single ear because some plants did not develop second productive ear at maturity although they showed multiple ears at silking. A balanced composite was made from at least 100 selected ears for the next cycle of selection. Four cycles of modified (partial control of pollen donors) mass selection for prolificacy were accomplished in 2006 and a total of nine populations including the initial population and eight improved populations were available for evaluation. Remnant seeds of these early populations were stored in cool room until they were used to avoid difference in seed vigor. A schematic diagram of four cycles of population improvement for prolificacy in a local variety of small ear waxy corn is presented in Fig. 1.

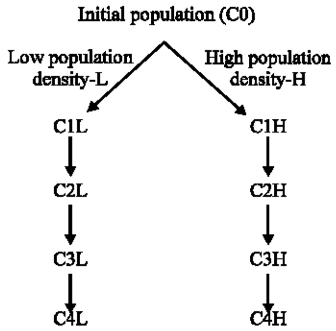

Fig. 1: Schematic diagram for population development of small ear waxy corn through modified mass selection for prolificacy for four cycles under low and high population densities

Field experiment: Nine populations of small ear waxy corn were evaluated for two seasons in the rainy season 2006 (May to July) and the dry season 2006/07 (November to January) at the Experimental Farm of Khon Kaen University. Dry crop is commercially practiced in Thailand, while rainy crop is rarely practiced and considered not profitable because of severe diseases and lodging. The experiment was laid out in 2×9 factorial combinations in a randomized complete block design with four replications. Two levels of plant densities (62,500 and 125,000 plants ha^{-1}) were assigned as factor A and nine populations as factor B. The plot size consisted of four rows with 5 m long and 3.2 m wide. Spacing arrangements for two plant densities were those mentioned previously in population development and selection procedure section. Conventional tillage was practiced for soil preparation and 15-15-15 fertilizer as basal dose at the rate of 171 kg ha^{-1} was incorporated into the soil during soil preparation. The seeds were over-planted and later thinned to obtain desired stands at seedling stage. Two splits of 15-15-15 fertilizer at the rate of 93.75 kg ha^{-1} plus urea (46-0-0) at the rate of 93.75 kg ha^{-1} for first split and 15-15-15 fertilizer at the rate of 125 kg ha^{-1} plus urea at the rate of 62.5 kg ha^{-1} for second split were applied to the crop at 14 days after planting (DAP) and 30 DAP, respectively. At flowering stage, 13-13-21 fertilizer was applied at the rate of 156.25 kg ha^{-1}. Therefore, there were a total dose of fertilizers of 150.65 kg ha^{-1} nitrogen, 78.78 kg ha^{-1} phosphorus and 91.27 kg ha^{-1} potassium, respectively. Sprinkler irrigations were supplied regularly to avoid drought stress and insect pests, diseases and weed were properly managed to obtain optimum growth and yield of the crop.

Days to 50% tasseling and silking were recoded from total number of plants in each plot. After tasseling, plant height and ear height were recoded from 10 randomly chosen plants in each plot. Plant height was measured from soil level to leaf collar of flag leaf, whereas ear height was measured from soil level to the node of the top ear. As low temperature delayed maturity, harvest times were determined as 16 days after silking in the rainy season and 24 days after silking in the winter season. Therefore, days to harvest were calculated as days to 50% silking plus 16 or 24 days for rainy season and winter season, respectively.

Harvest time for small ear waxy corn is somewhat later than that for sweet corn. It is equivalent to late R3 to early R4 growth stage with kernel moisture of about 70%. At harvest, ears with marketable size were considered harvestable (not all ears with kernels) and ear number per plant, ear diameter and ear length were recorded from 5-10 ears randomly chosen from all bordered plants in each plot, excluding plants at the end of row. Total number of ears were weighted and husked. Fresh kernels were separated from cops and un-husked weigh and husked weight ear on per harvest area of 6.72 m^2 were converted to per hectare.

Data analysis: The trial in the rainy season was not included in the analysis because of severe foliar diseases and stalk lodging. Growing small ear waxy corn is generally not profitable in the rainy season. Only the data in the dry season were subjected to analysis of variance followed a factorial experiment in RCBD (Gomez and Gomez, 1984). Corn population and plant population density were considered as fixed effects and replication as random effect. When main effect was significant, mean separation was performed using a LSD test at the 0.05 probability level. Linear regression analysis was also conducted to understand the relationship between selection cycles and number of ears plant^{-1}.

RESULTS

Responses to population density: Change in population density from 62,500 to 125,000 plants ha^{-1} resulted in significant increases in marketable ears, un-husked ear weight and husked ear weight (Table 1). The increases were from 128,863 o 199,703 ears ha^{-1} for marketable ears, 11,822 to 14,871 tons ha^{-1} for un-husked ear weight and 8,306 to 11,083 tons ha^{-1} for husked ear weight, with percent increases of 54.9, 25.8 and 33.4%, respectively. Plant height, ear height and days to silking were also increased slightly, which were not significantly different from those of the crop grown at lower population density. Increase in population density did not affect days to tasseling and ear diameter (data not provided), but it significantly reduced ear number per plant, kernel weight per ear and ear length. The reductions were from 2.06 ears per plants to 1.60 ears per plant, 41.5 to 36.2 g for kernel weight per ear and 11.0 to 10.1 cm for ear length, with percent reductions of 22.3, 12.8 and 8.2%, respectively (Table 1).

For all traits evaluated, the interactions between population and plant density were not significant, indicating that all populations in general responded similarly to plant density. However, differential responses to plant density in magnitude rather than in rank were observed between populations selected at low and those at high plant density for number of ears per plant, marketable ears, un-husked ear weight and husked ear weight (Table 2). Higher reduction in number of ears per plant (-26%) was found in populations selected at higher plant density compared to populations selected at lower plant density (-20.1%). In contrast to number of ears per plant, higher increases in marketable ears (+61.2%), green ear weight (+34.3%) and husked ear weight (+39.7%) were found in populations selected at lower plant density compared to the increases of 48.7, 17.5 and 26.5%, respectively, in populations selected at higher plant density. Higher plant density also reduced kernel weight per ear and ear length but the reductions were similar between populations selected at different densities, averaging -13.6 and -13.0% for kernel weight and -8.8 and -7.9% for ear length.

Responses to selection: As the interactions between population and plant density were not statistically

Table 1: Effects of population density on ear number, yield of marketable ears, un-husked ear weight, husked ear weight, kernel fresh weight per ear, ear length, plant height, ear height, days to tasseling and days to silking

Population density	Ears per plant (ear)	Marketable ears (ear ha^{-1})	Un-husked ear weight (t ha^{-1})	Husted ear weight (t ha^{-1})	Kernel fresh weight per ear (g)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to tasseling	Days to silking
62,500 plant ha^{-1}	2.06	128.863	11.822	8.306	41.5	11.0	152.2	78.5	45.3	46.9
125,000 plant ha^{-1}	1.60	199.703	14.871	11.083	36.2	10.1	157.9	86.0	45.3	47.5
Grand mean	1.83	164.283	13.346	9.695	38.9	10.6	155.1	82.2	45.3	47.2
Increase or reduction (%)	-22.30	+54.900	+25.800	+33.400	-12.8	-8.2	+3.7	+9.5	0	+1.3
LSD ($p \leq 0.05$)	0.13	1.519	169.000	112.000	2.0	0.5	NS	NS	NS	NS

NS: Not significant

Table 2: Responses of small ear waxy corn populations to population density (percent increase or decrease)

Population density	Ears per plant (ear)	Marketable ears (ear ha^{-1})	Un-husked ear weight (t ha^{-1})	Husted ear weight (t ha^{-1})	Kernel fresh weight per ear (g)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to tasseling	Days to silking
C0	-21.8	+61.8	+35.9	+49.3	-6.6	-4.6	+4.5	+9.4	-0.6	+0.5
Low density										
C1L	-15.5	+72.0	+55.2	+66.6	-14.4	-4.4	+5.6	+14.4	0.0	+1.1
C2L	-23.3	+57.1	+22.8	+32.2	-22.2	-4.4	+3.1	+5.5	+1.7	+1.6
C3L	-19.8	+57.8	+26.1	+36.5	-13.8	-12.2	+2.9	+9.2	-1.1	0.0
C4L	-21.7	+58.0	+33.3	+23.6	-4.1	-14.1	+6.5	+9.0	-1.6	+0.5
Mean	-20.1	+61.2	+34.3	+39.7	-13.6	-8.8	+4.5	+9.5	-0.3	+0.8
High density										
C1H	-24.4	+51.2	+21.5	+30.3	-13.2	-5.6	0.0	+8.2	+0.6	+2.2
C2H	-29.5	+43.4	+13.0	+22.9	-11.3	-8.9	+3.3	+11.7	+0.6	+2.7
C3H	-25.8	+49.5	+16.1	+26.6	-12.6	-10.9	+3.7	+10.3	+0.5	+2.7
C4H	-24.2	+50.7	+18.2	+26.2	-14.6	-6.3	+4.3	+8.1	+1.6	0.0
Mean	-26.0	+48.7	+17.2	+26.5	-13.0	-7.9	+2.8	+9.5	+0.8	+1.9

Table 3: Response to selection (combined from two population densities) of small ear waxy corn subjected to four cycles of modified mass selection for prolificacy at low and high plant population densities

Population density	Ears per plant (ear)	Marketable ears (ear ha^{-1})	Un-husked ear weight (t ha^{-1})	Husted ear weight (t ha^{-1})	Kernel fresh weight per ear (g)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to tasseling	Days to silking
C0	1.75	157.838	13.054	9.496	39.5	10.6	148.0	77.0	44.6	46.4
Low density										
C1L	1.66	151.631	12.361	8.846	39.5	10.6	151.0	76.7	44.3	45.8
C2L	1.74	156.071	13.057	9.325	40.8	10.6	152.0	80.5	45.1	47.4*
C3L	1.82	163.613	13.595	9.878	36.9	10.6	159.7*	85.5*	46.0*	48.0*
C4L	1.84	166.022	13.548	10.420	39.8	11.3	158.5*	84.2*	46.1*	47.9*
Mean	1.77	159334	13.140	9617	39.3	10.8	155.3*	81.7	45.4*	47.3*
High density										
C1H	1.88	167.919	13.584	9.740	38.2	10.5	153.9	80.1	44.4	46.8
C2H	1.86	164.526	13.238	9.450	37.0	9.9	156.4*	85.9*	44.9	47.4*
C3H	1.94*	173.538*	13.562	9.844	37.8	10.4	154.7	82.3*	45.6*	47.1*
C4H	1.99*	177.388*	14.117	10.252	40.5	10.7	161.4*	88.2*	46.6*	48.3*
Mean	1.92*	170843	13.625	9822	38.4	10.4	156.6*	84.1*	45.4*	47.4*
LSD ($p \leq 0.05$)	0.16	13.510	NS	NS	NS	NS	7.2	5.0	0.5	0.6

NS: Not significant. *Significantly higher than that of initial population

significant for all characters under study (Data not provided), the data at two population densities were combined (Table 3). Increase in ear number per plant as a result of modified mass selection for prolificacy was observed at both low and high densities and more evident at higher population density in which C3H and C4H populations (1.94 and 1.99 ears plant^{-1}, respectively) were significantly higher than initial population (C0) (1.75 ears plant^{-1}). Mean (1.92 ears plant^{-1}) for ear number per plant of populations selected at high plant density was significantly higher that of initial population, indicating the success of modified mass selection in increasing number of ears per plant. Estimates of selection response gave confirming results (Table 4). The genetic gains per cycle were 0.03 ($p \leq 0.01$) ears per plant and 0.05 ($p \leq 0.01$) ears per plant for selections at low and high population densities, respectively.

Similarly, the significant increases in marketable ears were also evident in C3H and C4H populations (173,538 and 177,338 ears ha^{-1}, respectively) compared with initial population (157,838 ears ha^{-1}) but not in C1L, C2L, C3L and C4L for populations selected at low density and in C1H and C2H for populations selected at high density (Table 3). Estimates of Gain per cycle were calculated as 2,835 ($p \leq 0.01$) and 4,471 ($p \leq 0.01$) ears ha^{-1} for populations selected at lower density and higher density, respectively (Table 4).

Un-husked ear weight and husked ear weight were slightly increased and not statistically different from those of initial population (Table 3). Although, population means are not statistically different, there were statistically significant for estimates of grain per cycle (Table 4). At lower density, estimates of gain per cycle were 222 ($p \leq 0.05$) and 288 ($p \leq 0.01$) kg ha^{-1} for un-husked ear weight and husked ear weight, respectively, whereas, at higher density, estimates of gain per cycle were 210 ($p \leq 0.05$) and 161 ($p \leq 0.01$) kg ha^{-1} for un-husked ear weight and husked ear weight, respectively. Estimates of gain per cycle of populations selected at lower density were somewhat higher than those of populations selected at higher density for both un-husked ear weight and husked ear weight.

Kernel weight per ear, ear length and ear diameter (data not provided) were not significantly affected by

Table 4: Estimates of responses to modified mass selection per cycle (b value) and estimates of correlated responses (r^c) of associated traits

Population density	Ears per plant (ear)	Marketable ears (ear ha^{-1})	Un-husked ear weight (t ha^{-1})	Husted ear weight (t ha^{-1})	Kernel fresh weight per ear (g)	Ear length (cm)	Plant height (cm)	Ear height (cm)	Days to tasseling	Days to silking
62,500 plant ha^{-1}	0.03**	2.835**	222.00*	288.00**	-0.20	0.14	2.90**	2.30*	0.48*	0.53*
125,000 plant ha^{-1}	0.05**	4.471**	210.00*	161.00**	0.20	0.01	2.80*	2.50*	0.53*	0.41*
r^c		0.99**	0.91**	0.76*	-0.21	-0.05	0.69*	0.74*	0.63	0.65

*,**Significant at 0.05 and 0.01 probability levels, respectively

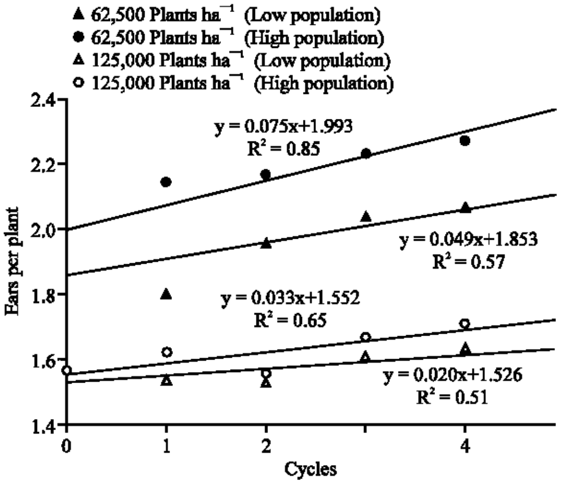

Fig. 2: Yield response (simple linear regression) to mass selection for ear per plant at low and high planting density of Tein Luang Nong Bua population

modified mass selection for prolificacy (Table 3). Estimates of genetic gain for these traits were also not significant (Table 4).

It is interesting to note that, apart from increases in ear yield both per plant and per unit area, modified mass selection for prolificacy also significantly increased plant height, ear height, days to tasseling and days to silking (Table 2). The significant increases in days to silking were found as early as cycle 2 in populations selected at both low and high population densities. Similarly, significant increases in plant height and ear height were observed as early as cycle 2 but in the populations selected at high plant density. In cycles 3 and 4, the increases in plant height, ear height, days to tasseling and days to silking became more pronounced. Estimates of genetic gain per cycle were also significant for plant height, ear height, days to tasseling and days to silking at either 0.05 or 0.01 probability level (Table 4).

Correlations between ear number per plant and its associated traits were significant for marketable ears (0.99**), un-husked ear weight (0.91**), husked ear weight (0.76*), plant height (0.69*) and ear height (0.74*) (Table 4). Number of ears per plant showed no association with kernel fresh weight, ear diameter (data not provided) and ear length. Although, they were not significant, intermediate and positive correlations were also found for days to tasseling (0.63) and days to silking (0.66) (Table 4).

Modified mass selection for prolificacy at higher population density seemed to be superior to that at lower population density (Fig. 2). Gain per cycle for number of ears per plant was 0.075 ears for the crop grown under high density, whereas only 0.049 ears per cycle was reached for populations selected at lower density. Similarly, when the populations were evaluated under lower plant density, gain per cycle was also higher (0.033) for populations selected at higher density compared to the gain of 0.020 for populations selected at lower density. It seems likely that higher population density favors the higher gain both in terms of selection and evaluation. However, mean differences between these selection methods were not statistically significant for ear yield both in terms of ear number per plant and ear weight per unit area, but both selection methods did increase ear yield (Table 3).

DISCUSSION

Responses to population density: The initial population was selected for this study because of its tendency to prolificacy, producing 1-4 ears. Because small ear waxy corn in Thailand is typically marketed on per ear basis, high number of marketable ears per unit area is more profitable than high un-husked ear weight. Therefore, improvement of green ear yield is the main objective of this research. However, ear characters of the improved populations should be in the range of the standard of marketable ears. According to the Department of Agriculture (1996), husked ears should have ear length of 10-15, 2-3 cm in ear diameter measured at the center of ears and 8-12 kernel rows. In this study, the effects of population density on ear number and related traits were evaluated to understand the extent to which these traits are affected.

The results showed that higher ear yield with regard to ear number and ear weight per unit area was obtained from the crop grown under higher planting density (125,000 plants ha^{-1}). In this regards, present results supported well the previous studies which reported that higher ear number was obtained under higher population density (Uhr and Goodman, 1995; Maita and Coors, 1996; Jampatong *et al*., 2000). The increase in ear yield as affected by high plant density was on the expense of number of ear per plant. Ear yield in small ear waxy corn seemed to be density-dependent. This was more pronounced for populations selected at low population density, whereas populations selected at high density was less dependent on high population density to achieve high yield. This would be attributed to higher potential of prolificacy in these populations. The results were in accordance with the report of Ipsilandis and Vafias (2005) who mentioned that yield of modern maize hybrids is dependent on high plant densities.

High density had deleterious effects on ear length and kernel fresh weight. This means that high population density resulted in smaller ears. Therefore, optimum population density is required for optimum yield and quality of small ear waxy corn. However, optimum population density is difficult to determine because there have interactions with environmental factors such as soil moisture, weed interference, soil types, tillage practices, diseases and pests, available nutrients and weather conditions especially for air temperature and solar radiation (Martin and Lindquist, 2007). As small ear waxy corn has much smaller plants than normal grain maize, the density of 125,000 plants ha^{-1} with two plants per hill can give acceptable yield and should be recommended to farmers.

The reduction in ears per plant was higher in populations selected at high population density than that selected at low plant density. This is attributed to higher ears per plant of populations selected at high population density when grown at low population density. Although, they had high reduction in ears per plant, they were still superior to populations selected at low population density when grown at high density. The results suggested that populations with higher prolific potential can produce more ears at higher population density when compared with populations with lower prolific potential.

In contrast to ears per plant, there were higher percent increases in marketable ears, un-husked ear weight and husked ear weight in populations selected at low population density. The results indicated that yield of populations selected at lower population density was more dependent on high plant density than populations selected at high plant density. Populations with lower prolific potential can give high yield only at optimum population density.

The responses of populations selected at different population densities were similar for kernel fresh weight, ear length, plant height, ear height, days to tasseling and days to silking. This would be due to the fact that all populations are genetically related and selection for prolificacy for four cycles had low effect on these traits.

Responses to selection: Selection for prolificacy in maize has been recommended as an effective method to improve grain yield (Coors and Mardones, 1989). The results of selection for prolificacy in our study did increase number of reproductive ears. However, the results did not show significant increase in grain yield. Similar to our results, Bento *et al*. (2003) did not found significant increase in grain yield of maize populations selected for prolificacy for six cycles although prolificacy characters showed a small increase with selection. This could be because of low variability of the prolificacy characters or low heritability of grain yield. Therefore, it might be difficult to improve grain yield through mass selection for prolificacy within few cycles of selection. However, long term selection might improve grain yield and more prolific plants. In a classical long-term selection in golden glow population, ear number increased from 1.61 ears at C0 to 4.93 ears at C24 and the more advanced cycles had progressively greater yield at higher plant densities (optimum at 310, 000 plants ha^{-1}) than earlier cycles (de Leon and Coors, 2002). Incorporation of exotic germplasm to widen genetic base should increase the efficiency of selection.

Although, ears per plant and marketable ears were significantly increased, the increases were rather low because the control of pollination was not effective enough and un-selected plants still gave pollens to next generation. Selection schemes that give more effective control of pollination such as full-sib recurrent selection should yield higher gain per cycle. However, more time is required to complete a cycle because this selection method requires progeny test.

Surprisingly, selection at higher population density had higher genetic gain than the one at lower population density for number of ears per plant and marketable ears. In previous studies in grain maize, selection at higher population density was less efficient than selection at lower population density (Singh *et al*., 1986). However, Bento *et al*. (2003) observed that the efficiency of mass selection for prolificacy did not depend on the plant densities used. Higher intra-plant interference at higher population density causes high variation of individuals (Ipsilandis and Vafias, 2005). Therefore, it is more difficult to identify superior genotypes at high population density. At lower population density, in contrast, individual plants have low competition for water, nutrients and solar radiation, Therefore, identification of superior genotypes should be more effective at lower population density than at higher population density.

The higher genetic gain of selection at higher population density in this study is difficult to explain. It might be possible that plants expressing high prolificacy show more prolific ears than plants with lower levels of prolificacy at higher population density and prolificacy is highly heritable in this population and variation in population density has less effect on this trait at least in the range of population in this study. The results unique to our experiment are that at high population density we grew two plants per hill and this practice might promote vigorous growth of prolific plants when the population is heterogeneous. Other reason is that selection intensity is double at high density population.

Increases in ears per plant and marketable ears were associated with taller plants higher ears and more days to tasseling and to silking. This is because of competitive plants could produce more ears under population stress. Prolificacy is associated with elongation of internodes near productive ears. Higher plants and higher ears are not preferable because they have tendency to lodging. These plants also had tendency to late maturity because they needed more assimilates to support productive ears, resulting in the delay of tasseling and silking. Small ear waxy corn in Thailand is much earlier mature than normal grain maize. Growers prefer early maturing varieties to obtain higher price at early season. Therefore, late maturity would be a negative effect.

Selection for prolificacy did not significantly affect kernel fresh weight per ear, ear diameter and ear length. The results indicated that ear size was not reduced by increased number of ears. As Small Ear Waxy Corn Khon Kaen Composite is marketed on number of ear basis, the responses for these traits are considered favorable.

CONCLUSION

Because of crop failure in the rainy season, conclusion has been made from only the data in the dry season and the research was discontinued because of limited time frame and funding. Some aspects such as interactions between years have not been answered. Based on the results, high plant density (125,000 plants ha^{-1}) with two plants per hill (to facilitate manual planting operation) is recommended for farmers who want to grow small ear waxy corn commercially. Growing in the rainy season is not recommended because of severe diseases and lodging. For response to selection, the data of two plant densities showed very consistent information. Genetic gains from selection for ear number per plant and green ear yield were obtained from either selection at lower or higher population density. Mass selection for prolificacy at higher plant density (125,000 plants ha^{-1}) was somewhat superior to the one at lower population density. The results were opposed to many studies conducted in maize which reported better gains at lower population density and further investigations may elucidate this question.

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