Turkish Journal of
Field Crops
2014, 19(1), 84-89

YIELD AND EARLY MATURITY RESPONSE TO FOUR CYCLES OF MODIFIED MASS SELECTION IN PURPLE WAXY CORN

Satang HUSSANUN[1], Bhalang SURIHARN[1, 2], Kamol LERTRAT[1, 2]*

[1]*Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, THAILAND*
[2]*Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Khon Kaen, THAILAND*
**Corresponding author: bsuriharn@gmail.com.*

Received: 15.01.2014

ABSTRACT

High yield and early maturity are important characters in corn breeding. The objectives of the study were to evaluate the responses to four cycles created by modified mass selection method to increase yield and early maturity of a purple waxy and to investigate the correlations between yield and among other important traits in a purple waxy corn (*Zea mays* L. var. *ceratina*) population. Four cycles was evaluated for two seasons in 2012/13. A randomized complete block design with four replications was used. The results indicated that the selection method has led to improvement in many characters of this population. C_4 cycle gave the highest whole ear yield of 16.0 t ha^{-1} followed by 15.4 t ha^{-1} of C_3 cycle. Although C_4 also had the highest marketable husked yield (9.9 t ha^{-1}), it had the lowest days to tasseling and days silking. Genetic gains per cycle were 0.68 (P≤0.01) and 0.37 (P≤0.01) for whole ear yield and marketable husked yield, respectively, whereas genetic gain for days to tasseling and silking was -1.8 for both traits. As correlations between marketable husked yield with days to silking and days to tasseling were negative and low, direct selection for marketable husked yield would result in early maturity in this corn population, and several generations of recurrent selection are required.

Keywords: *Zea mays* L. var. *ceratina*, corn breeding, population improvement, correlation, indirect selection

INTRODUCTION

Corn is an important food crop in the world. Waxy corn that is a special corn type can be used as food in several countries and as replacement for dent corn for animal feed (Johnston and Anderson 1992; Schroeder et al., 1998). Moreover, waxy corn starch is unique and has high amylopectin content, which gives high possibilities in industrial use (Klimek-Kopyra et al., 2012). Corn has a wide range of kernel colors such as white, yellow, black and purple. There are numerous special cultivars that contain colored pigments and give rise to numerous varieties of black and purple corn. The dark purple color of corn is caused by high content of anthocyanins located in the pericarp layers and cob. Anthocyanin pigment was found in all parts of purple corn, but it was found at particularly high concentration in the husk and cob (Li et al., 2008). Studies on antioxidant and anticarcinogenic properties of anthocyanin has been conducted mainly in normal purple corn, making it more attractive for nutraceutical and functional food market (Cevallos-Casals and Cisneros-Zevallos, 2003; 2004). Kernels and cobs of purple corn possessed excellent antioxidant activity, and the application of these natural food colorants by the food industry would be increased considerably (Yang and Zhai 2010). Therefore, it is important to breed waxy corn for high anthocyanin.

High yield is still a primary goal of most plant breeding programs (Ferh 1987). Pest resistance, stalk strength, uniformity, kernel quality and early maturity are also important in corn and waxy corn breeding programs. Currently, most corn varieties grown commercially are hybrids. However, some waxy corn varieties in Asian counties are open-pollinated varieties (OPVs). Therefore, improved OPVs are important in the countries where seed production is not well developed, and they also have potential as germplasm sources for hybrid development. OPVs with high yield or good adaptation are excellent germplasm sources for corn breeding programs.

Mass selection is the simplest and inexpensive method for population improvement in cross pollinated crops, and this method could be effective for selection of the traits that can be identified before or at the time of flowering (Vasal et al., 2004). However, the method is not effective for improvement of crop yield or quantitative characters because only female plant is selected. Recently, modified mass selection for prolificacy and ear length has been used effectively for yield improvement in waxy corn (Kesornkeaw et al., 2009; Senamontry et al., 2013).

However, the information on population improvement for high yields and early maturity are still lacking in corn and purple waxy corn. Previously study in field maize indicated that simultaneous improvement of these traits is difficult due to positive correlation between yields and maturity in maize (Beck et al., 1990; Konak et al., 1997).

Vegetable waxy corn with early maturity and high yield is required for specific cropping systems that have a limited time to grow waxy corn with late maturity. Is it possible to select purple waxy corn for early maturity for some extent without significant yield reduction? To respond to this question, mass selection experiment was carried out for four cycles. The objectives of this research were to evaluate the response to modified mass selection for yields and maturity of a purple waxy corn population, KND composite #1, and to investigate correlations between yields and among other important traits.

MATERIALS AND METHODS

Plant materials

Three corn populations (PFC, HJ and SLE) with different kernel and cob colors were used to generate new population for selection experiment. PFC is a field corn population with purple kernels and purple cobs, high yield, late maturity, HJ is a waxy corn with white kernels, white cobs, good eating quality, stay green, good stand ability, high yield and medium maturity, and SLE is an OPV waxy corn population with white kernels, white cobs, good eating quality, medium yield and early maturity.

Population improvement

The base population of waxy corn, Khon Kaen KND composite #1, was developed from three populations (PFC, HJ and SLE) in 2008 to 2009 at the Experimental Farm, the Faculty of Agriculture, Khon Kaen University, Thailand. Two hundred plants in each population were used to create new population. At two or three days after silking, bulked pollens from all plants of HJ were used to pollinate all ears in PFC population in the rainy season 2008, and all pollinated ears in PFC population were harvested. The F_1 generation was further backcrossed to HJ population in the dry season 2008/2009.

The seeds of the backcross generation were mixed with the seeds of SLE population in the same proportion in the rainy season 2009. The bulked seeds were sown for two seasons to create a random mating base population. The seeds showing waxy endosperm were selected from the F_2 generation using potassium iodide (KI). A blue-black color indicates that the seeds are field corn, and red color shows that the seeds are waxy corn. The population was then developed to improve yield and earliness through modified mass selection method.

Modified mass selection was carried out consecutively for four cycles. Selection from C_0 generation to C_4 generation was performed at spacing of 0.80 x 0.25 m which provided population density of 8,000 plants per 0.16 ha^{-1}. Plants of about 10 percent in each cycle were used for generation advance, and remnant seeds were stored in a refrigerator for further evaluation. Before silk emergence, bulked pollens from selected plants with purple kernels, purple cobs, early maturity, good stand ability, big ears and disease free were used to pollinate all ears of selected plants. C_4 population was completed in the rainy season 2012.

Field Experiment

The experiment was conducted in the late rainy season 2012 and dry season 2012/2013 at the Experimental Farm, Khon Kaen University, Thailand (16º47′ N, 102º81′ E, 200 msl). Five populations of purple waxy corn (C_0 to C_4) were evaluated in a randomized complete block design with four replications for two seasons.

The plot size was four-row plot with five meters in length and spacing of 0.80 x 0.25 m. Conventional tillage was practiced for soil preparation, and 15-15-15 fertilizer of N-P-K as basal dose at the rate of 171 kg ha^{-1} was incorporated into the soil during soil preparation. 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, total dose of fertilizers consisted of 150.65 kg ha^{-1} nitrogen, 78.78 kg ha^{-1} phosphorus and 91.27 kg ha^{-1} potassium, respectively. Irrigation was supplied regularly to avoid drought stress, and insect pests, diseases and weed were appropriately managed to obtain optimum growth and yield of the crop for both seasons.

Data collection

Data were recorded for whole ear yield, marketable husked yield, ear diameter, ear length, plant height, ear height, days to tasseling and days to silking. Days to 50% tasseling and silking were recorded from total number of plants in each plot. After pollination, plant height and ear height were recorded from 10 randomly chosen plants in each plot. Harvest time was determined at 20 days after pollination (R4 growth stage). All ears from the center two rows or 40 plants were harvested and weighed. Ear diameter, ear length and marketable husked yield were recorded from good 10 representative ears in each plot.

Data analysis

Analysis of variance was performed for each character in each season. A combined analysis of variance of two seasons was conducted when error variances of two seasons were homogeneous, and the ratio of error variances between two seasons was smaller than 3 (Gomez and Gomez 1984). Significant differences among cycles were assessed by least significant difference (LSD) at *0.05* probability level, and all analyses were carried out using MSTAT-C software (Russel 1994). Regression analysis was used to evaluate the correlated responses to selection for studied traits. Response to selection was determined by simple linear regression. Difference from zero of b values was determined by T-test.

RESULTS AND DISCUSSION

Analysis of variance

Seasons were significantly different for whole ear yield, days to tasseling and days to silking, and cycles were significantly different for most (Table 1). Differences in seasons indicated that environment was important for the expression of these traits in waxy corn, and differences in cycles indicated the significant effects of modified mass selection on these traits. However, interactions between season and cycle were not significant for all traits. Low interactions indicated that the cycles responded similarly for all traits in both seasons.

Table 1. Mean square for yield, yield component and agronomic traits of five cycles purple waxy corn population across two seasons 2012/13.

Df	**1**	**6**	**4**	**4**	**24**	
Trait	**Mean square**					**C.V. (%)**
	Season (S)	**Rep./S**	**Cycle (C)**	**S x C**	**Pooled error**	
Yield trait						
Whole ear yield (t ha^{-1})	16,650**	1,200	9,708**	640ns	791	6.1
Marketable husked yield (t ha^{-1})	87ns	478	3741**	317ns	664	9.2
Yield components						
Ear diameter (cm)	0.03ns	0.02	0.25**	0.01ns	0.02	3.3
Ear length (cm)	9.4ns	2.8	6.3**	0.4ns	0.5	4.3
Agronomic traits						
Plant height (cm)	1ns	171	678**	15ns	17	1.9
Ear height (cm)	244ns	536	1,625**	458ns	175	11.3
Day to tasseling (day)	518.4**	1.0	63.2**	1.5ns	0.8	1.8
Day to silking (day)	403.2**	2.0	66.9**	1.2ns	1.1	2.1

ns = non significant
** = significant at P < 0.01, respectively

Response to selection

C_4 cycle had the highest whole ear yield of 16.0 t ha^{-1} followed by C_3 cycle with whole ear yield of 15.4 t ha^{-1} (Figure 1). C_4 Cycle also had the highest marketable husked yield of 9.9 t ha^{-1} followed by 8.9 t ha^{-1} of C_3 cycle. Genetic gains per cycle were 0.68 ($P \leq 0.01$) and 0.37 ($P \leq 0.01$) for whole ear yield and marketable husked yield, respectively (Figure 1).

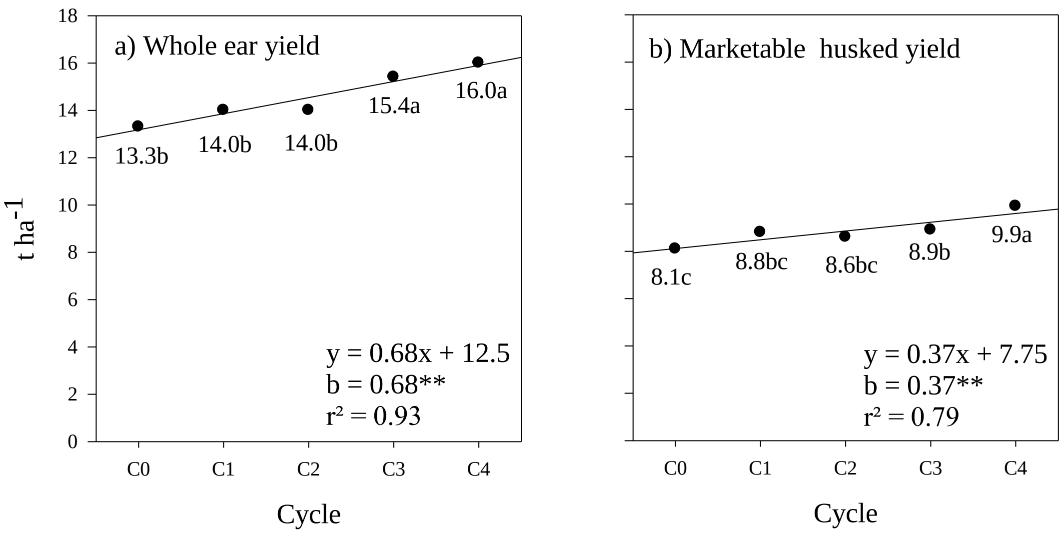

Figure 1. Means for yields of five cycles of purple waxy corn populations. Letters at least one same letter indicate non-significant difference by LSD. ** b-values are significantly different from zero at P < 0.01.

In previous study, modified mass selection could improved prolificacy, yield and ear length in waxy corn (Kesornkeaw et al., 2009; Senamontry et al., 2013). Seven selection methods (mass, modified ear-to row, half-sib with inbred tester, full-sib, S1-progeny, S2-progeny, and reciprocal full-sib selection) were successful in significantly improving the population per se performance for grain yield in the BS11 maize population (Weyhrich et al., 1998). The results are supported by previous findings and ensure the usefulness of modified mass selection for yield improvement in waxy corn.

Cycle C_4 and cycle C_3 had the biggest ears with diameters of 4.5 and 4.4 cm, respectively (Figure 2). Ear lengths for C_4, C_3, C_2 and C_1 were 18.5, 17.4, 17.0 and 16.8 cm, respectively. Genetic gains of 0.11 and 0.54 cm per cycle were observed for ear diameter and ear length, respectively. The results indicated that yield of waxy corn could be improved by selection for larger and longer ears.

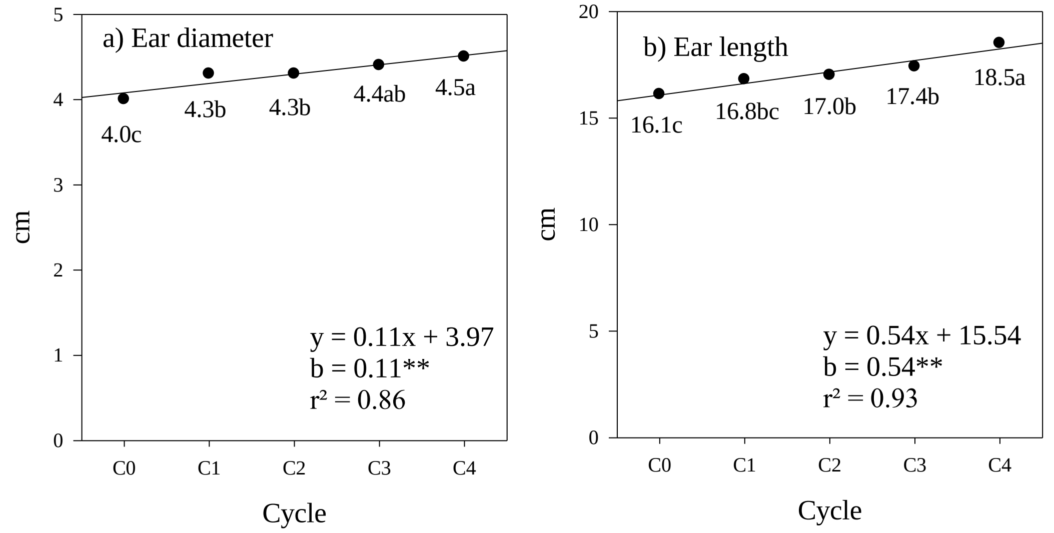

Figure 2. Means for yield components of five cycles of purple waxy corn populations. Letters at least one same letter indicate non-significant difference by LSD. ** b-values are significant different from zero at $P < 0.01$.

Plant heights for C_4, C_3, C_2, C_1 and C_0 were 201, 207, 215, 220 and 223 cm, respectively, and ear heights were 105, 106, 116, 118 and 104 cm in respective order (Figure 3). Gains per cycle were estimated at -0.57 cm ($P \leq 0.01$) for plant height and -8.2 cm ($P \leq 0.01$) for ear height. Carena and Cross (2003) found in maize that mass selection at high plant population densities resulted in taller plants with high ears, and selection at high planting densities did not produce population with improved ability to withstand high densities. Plant population density affected crop yield and response to selection through the increase in competition (Fasoula and Tollenaar, 2005). In this study, modified mass selection reduced plant height and ear height, and these effects are preferable because shorter plants are more resistant to lodging. Plant population density used in this study was optimum to produce shorter plants with lower ear placement.

It should be noted that modified mass selection for yield resulted in the reduction in days to tasseling and days to silking in M_4 population (45 and 46 days, respectively), and gain per cycle of selection was estimated at -1.8 for both traits. It had a tendency to obtain early maturity plants in response to selection for yield. The effect of modified mass selection for yield on maturity is preferable as early maturity is more suitable to many cropping systems.

The results in this study did not support previous findings. Selection for yield in maize resulted in the increase in maturity (Beck et al., 1990; Konak et al., 1997). The differences in the results could be due to the fact that some crops obtain high yield though high biomass, but some crops obtain high yield thought effective partitioning of biomass into harvestable yield.

Correlated response

The correlation coefficients between whole ear yield with marketable husked yield ($r=0.71$, $P \leq 0.01$), ear diameter ($r=0.58$, $P \leq 0.01$) and ear length ($r=0.33$, $P \leq 0.05$) were positive and significant, but whole ear yield was negatively correlated with plant height ($r=-0.54$, $P \leq 0.01$) and ear height ($r=-35$, $P \leq 0.05$) (Table 2). Whole ear yield was not significantly correlated with days to tasseling ($r=0.02$) and days to silking ($r=-0.07$). Similar correlation coefficients were observed for marketable husked yield with ear diameter, ear length, plant height and ear height. However, the correlation coefficients between marketable husked yield with days to tasseling ($r=-0.22$) and days to silking ($r=-0.28$), although they were not significant, was positive and much higher than those with whole ear yield.

In previous investigations, yield was negatively and significantly correlated with days to silk (Konak et al., 1997), and maize genotypes with early maturity had lower yield of about 20-30% than did the genotypes with late maturity (Beck et al., 1990). in wheat, grain yield was positively correlated with maturity, rate and duration of grain fill, and harvest index (Iqbal et al., 2007). The improved C_4 population had high yield and early maturity through modified mass selection. Harvest index should be a factor determining yield increase in this population.

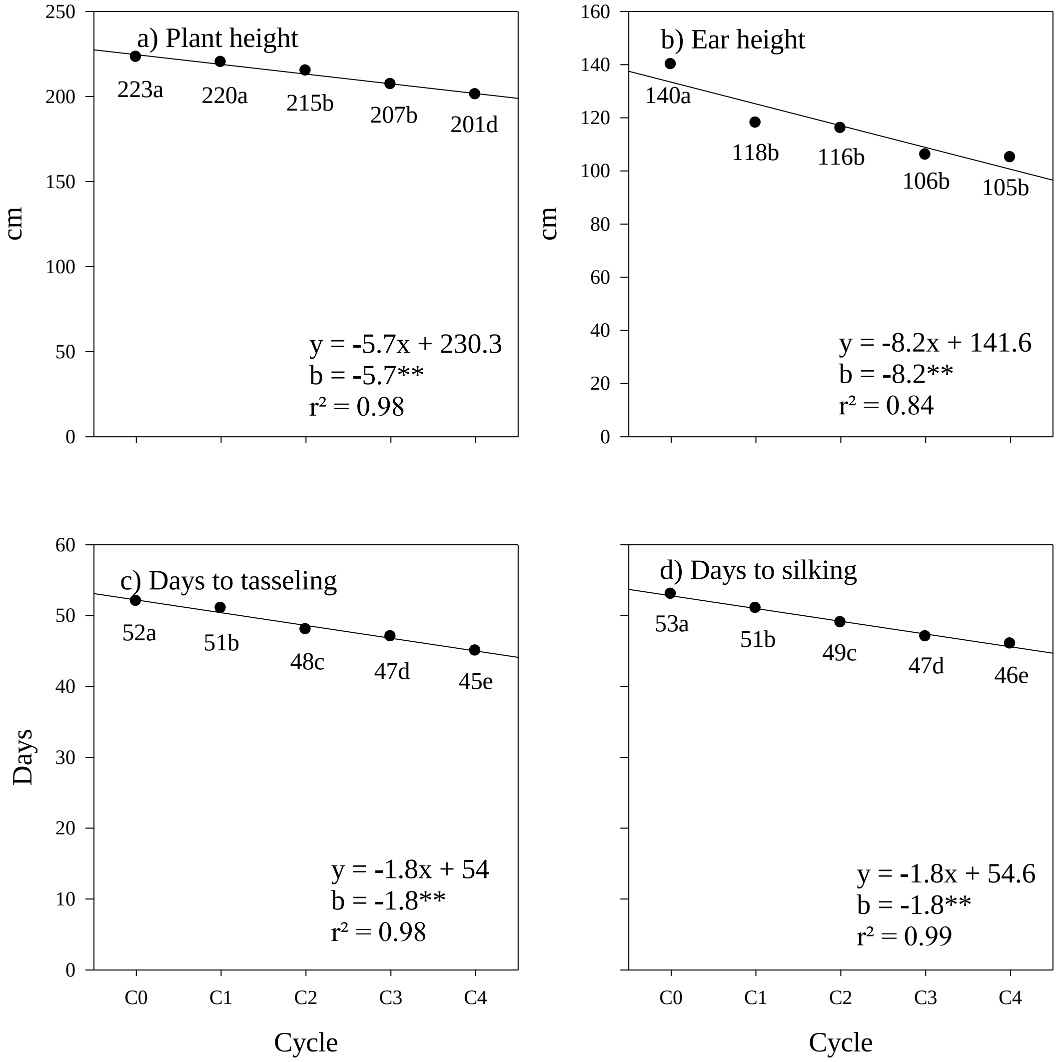

Figure 3. Means for agronomic traits of five cycles of purple waxy corn populations. Letters at least one same letter indicate non-significant difference by LSD. ** b-values are significant different from zero at $P < 0.01$.

Table 2. Correlations among yields, yield components and agronomic traits (n=40).

	Whole ear yield	Marketable husked yield	Ear diameter	Ear length	Plant height	Ear height	Days to tasseling
Marketable husked yield	0.71**						
Ear diameter	0.58**	0.53**					
Ear length	0.33*	0.43**	0.46**				
Plant height	-0.54**	-0.40*	-0.55**	-0.38*			
Ear height	-0.35*	-0.35*	-0.49**	-0.18	0.65**		
Days to tasseling	0.02	-0.22	-0.28	-0.62**	0.46**	0.26	
Days to silking	-0.07	-0.28	-0.31*	-0.62**	0.53**	0.32*	0.98**

*, ** = significant at $P < 0.05$ and $P < 0.01$, respectively

Ear diameter was closely associated with ear length (r=0.46, P≤0.01). However, these traits were negatively associated with plant height, ear height, days to tasseling and days to silking although the correlation coefficients between days to tasseling with ear diameter (r=-0.28) and ear height with ear length (r=-0.18) were not significant. Plant height, ear height, days to tasseling and days to silking were interrelated as most correlation coefficients were positive and significant except for the correlation coefficient between days to tasseling with ear height (r=0.26).

In conclusion, modified mass selection was successful in developing high yield and early maturity population of waxy corn from the base population Khon Kaen KND composite #1. Whole ear yield, marketable husked yield, ear diameter and ear length were significantly increased, whereas modified mass selection resulted in reductions in days to tasseling, days to silking, plant height and ear height. The responses to selection are preferable because the new population have better agronomic traits. Early maturity is more suitable for many cropping system, and shorter plants with lower ear placement are more resistant to lodging. As correlations between whole ear yield with days to tasseling and days to silking were not significant, selection for early maturity for a limited extent would not detrimental to whole ear yield.

Modified mass selection is a rapid and convenient method for population improvement for yield and purple density of kernels and cops in purple waxy corn as a cycle of selection can be completed in one season and both male and female parents can be selected. However, purple color is a complex character, and kernel color segregates in the improved population. More cycles of recurrent selection for purple color is still required to eliminate segregating progenies in the population. This improved population (C_4) can be used as OPVs or germplasm source for high yield and early maturity in purple corn breeding programs.

ACKNOWLEDGMENTS

We are grateful for the financial support provided by the National Center for Genetic Engineering and Biotechnology, Bangkok, Thailand and the Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Thailand. Acknowledgement is extended to Khon Kaen University and the Faculty of Agriculture for providing financial support for manuscript preparation activities.

LITERATURE CITED

Beck, D.L., S.K. Vasal and J. Crossa. 1990. Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize (*Zea mays* L.) germplasm. Maydica 35: 279-85.

Cerena, M.J. and H.Z. Cross. 2003. Plant density and maize germplasm improvement in the Northern corn belt. Maydica 48: 105-111.

Cevallos-Casals, B.A. and L. Cisneros-Zevallos. 2003. Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweet potato. J. Agric. Food Chem. 51: 3313-3319.

Cevallos-Casals, B.A. and L. Cisneros-Zevallos. 2004. Stability of anthocyanin-based aqueous extracts of Andean purple corn and redfleshed sweet potato compared to synthetic and natural colorants. Food Chem. 86: 69-77.

Fasoula, V.V. and M. Tollenaar. 2005. The impact of plant population density on crop yield and response to selection in maize. Maydica 50: 39-48.

Fehr, W.R. 1987. Principle of Cultivars Development. New York: McMillan publ. company.

Gomez, K.A. and A.A. Gomez. 1984. Statistical Procedure for Agricultural Research. 2. ed. New York: John Wiley & Sons.

Iqbal, M., A. Navabi, D.F. Salmon, R.C. Yang and D. Spaner. 2007. Simultaneous selection for early maturity, increased grain yield and elevated grain protein content in spring wheat. Plant Breeding126: 244-250.

Johnston, L.J. and P.T. Anderson. 1992. Effect of waxy corn on feedlot performance of crossbred yearling steers. Minnesota Beef Cattle Research Report. pp. 1–5.

Kesornkeaw, P., K. Lertrat and B. Suriharn. 2009. Response to four cycles of mass selection for prolificacy at low and high population densities in small ear waxy corn. Asian J. Plant Sci. 8: 425-432.

Klimek-Kopyra, A., A. Szmigiel, T. Zając and A. Kidacka. 2012. Some aspects of cultivation and utilization of waxy maize. Acta Agrobot. 65: 3-12.

Konak, C., A.Ünay, A. Zeybek and E. Acartürk. 1997. Correlation and path analyses in maize (*Zea mays* L.). Turk. J. Field Crops 2: 47-52.

Li, C.Y., H.W. Kim, S.R. Won, H.K. Min, K.J. Park, J.Y. Park, M.S. Ahn and H.I. Rhee. 2008. Corn husk as a potential source of anthocyanins. J. Agric. Food Chem. 56: 11413-11416.

Weyhrich, R.A., K.R. Lamkey and A.R. Hallauer. 1998. Responses to Seven Methods of Recurrent Selection in the BS11 Maize Population. Crop Sci. 38: 308-321.

Russel O.F. 1994. MSTAT—C v.2.1 (a computer based data analysis software). Michigan: Crop and Soil Science Department, Michigan State University.

Schroeder J.W., G.D. Marx and C.S. Park. 1998. Waxy corn as a replacement for dent corn for lactating dairy cows. Ani. Feed Sci. Tec. 72: 111-120.

Senamontry, K., K. Lertrat and B. Suriharn. 2013. Response to five cycles of modified mass selection for ear length in waxy corn. Sabrao J. 45: 332-340.

Vasal, S.K., N.N. Singh, B.S. Dhillon and S.J. Patil. 2004. Population improvement strategies for crop improvement. In: Plant Breeding-Mendelian to Molecular Approaches, ed. Jain H.K., and Kharkwan M.C., 391-406, Narosa Publishing House, New Delhi.

Yang, Z. and W. Zhai. 2010. Identification and antioxidant activity of anthocyanins extracted from the seed and cob of purple corn (*Zea mays* L.). Innovative Food Sci. Emerging Technol. 11: 169-176.