Indonesian Journal of Agricultural Science 8(1), 2007: 1-9

SELECTION RESPONSE FOR INCREASED GRAIN YIELD IN TWO HIGH OIL MAIZE SYNTHETICS

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ABSTRACT

Selection for increased oil level in maize showed the increase was associated with decrease in starch concentration, kernel weight, and grain yield. The study was conducted with the objectives: (1) to evaluate response to six cycles for increased grain yield in the high oil maize Alexho Elite (AE: 60-90 g kg^{-1} oil concentration) and Ultra High Oil (UHO: 100-140 g kg^{-1} oil concentration) using inbred tester B73; (2) to measure responses to selection for increased grain yield with changes in yield components; and (3) to determine a suitable tester. Previously the two synthetics had been selected for oil concentration. After six cycles, the six genotypes i.e. AE C0, AE C3, AE C6, UHO C0, UHO C3, and UHO C6 were testcrossed to B73, LH185, and LH202 inbreds (40 g kg^{-1} oil concentration) to a total of 18 testcrosses. Two field experiments were used to evaluate selection in AE and UHO testcrosses. The study showed selection using inbred tester B73 in AE and UHO was effective in increasing grain yield of AE testcrosses without changing (i.e. decreasing) oil and protein concentrations. AE testcrosses produced higher grain yield and greater selection response for grain yield than UHO testcrosses. LH185 was best for grain yield in AE and UHO testcrosses. Increase in grain yield in most of the testcrosses was associated with increases in starch concentration, kernel weight, kernel number, and grain weight.

[***Keywords***: *Zea mays*, maize, synthetic, yield, inbred, testcross]

INTRODUCTION

Long term selection for high oil concentration in maize (*Zea mays* L.) was begun in the Burr's White maize cultivar in 1896 (Woodworth *et al.* 1952). Responses to selection have been reported periodically. Woodworth *et al.* (1952) reported oil concentrations of the Illinois High Oil (IHO) and Illinois Low Oil (ILO) strains were 154 and 10 g kg^{-1}, respectively, after 50 generations of selection, compared to 47 g kg^{-1} in the original cultivar. Dudley *et al.* (1974) reported selection progress after 70 generations of IHO maize strains. The mean oil concentration of the 70^{th} generation in IHO was 166 g kg^{-1}, or an increase of 355% compared to the original cultivar. Dudley and Lambert (1992) reported selection progress of IHO and the Illinois High Protein (IHP) strains after 90 generations and a total of 220 g kg^{-1} oil and 320 g kg^{-1} protein were respectively observed in IHO and IHP. In IHO, each 10 g kg^{-1} increase in oil was associated with 13-16 g kg^{-1} decrease in starch. In IHP, each 10 g kg^{-1} protein increase was associated with 10 g kg^{-1} decrease in starch.

Thirteen generations of reverse selection were conducted after 48 generations of regular selection for oil and protein concentrations of four Illinois chemical strains of maize. Selection in the Reverse High Oil (RHO) strain reduced oil levels from 135 to 100 g kg^{-1}, compared to 146 g kg^{-1} in regular IHO (Leng 1962). Curtis *et al.* (1968) evaluated developmental changes in oil and fatty acid composition in the Illinois maize strains (IHO, RHO, ILO, and Reverse Low Oil). After 65 generations of selection in IHO, total germ weight and percentage increased.

Selections for increased oil concentration in other maize populations were included. Misevic and Alexander (1989) reported progress of 24 cycles of single kernel recurrent selection increase oil concentration in Alexho Single Kernel (ASK) synthetic. The same cycles were crossed to inbreds B73 and R802A. After 24 cycles of selection, total oil concentration in the cycles increased by 118 g kg^{-1} or the response rate per cycle was 4.9 g kg^{-1}. In testcrosses to B73 and R802A, oil concentration increased by 51 and 57 g kg^{-1} or response rate per cycle was 2.1 and 2.4 g kg^{-1}, respectively. However, increases in oil levels were associated with decreases in grain yield of 71.6 kg ha^{-1} per cycle in the cycles. In the testcrosses to inbreds B73 and R802, grain yield decreased 19.7 and 15.2 kg ha^{-1} per cycle, respectively.

Seven cycles of high-intensity within half-sib family single-kernel selection for increase oil concentration in Armel's Reid Yellow Dent maize cultivar were reported by Miller *et al.* (1981). Oil concentration increased from 40 g kg^{-1} in cycle-0 to 91 g kg^{-1} in cycle-7, or 6.7 g kg^{-1} oil per cycle, without a significant change in grain yield. Evaluation for oil increase in ASK synthetic (Lambert *et al.* 1997) for 20 cycles of single kernel recurrent selection showed a significant increase in oil concentration from 51 g kg^{-1} in cycle-0 to 135 g kg^{-1} in cycle-20, or 4.1 g kg^{-1} per cycle. However, a decrease in starch concentration of 3.5 g kg^{-1} per cycle was also observed.

Selection response for increased grain yield in high oil has not been reported. The objectives of this study were: (1) to evaluate recurrent selection for increased grain yield in the high oil maize synthetics Alexho Elite (AE) and Ultra High Oil (UHO) using the inbred tester B73; (2) to measure responses to selection for increased grain yield in yield components; and (3) to determine a suitable tester in these two high oil maize synthetics.

MATERIALS AND METHODS

Origin of High Oil Maize Synthetics

Six cycles of high grain yield recurrent selection, using an inbred tester B73, were completed in two maize synthetics: AE (60-90 g kg^{-1} oil level) and UHO (100-140 g kg^{-1} oil level). These two synthetics were developed from different cycles of ASK that originate from intermating in isolation of 56 open-pollinated cultivars (varieties and synthetics). Starting in 1964, a single kernel selection was applied using a Nuclear Magnetic Resonance Spectroscopy and the process was continued with 125 families through 1987 (Alexander 1988).

AE synthetic was developed from seven inbreds (R804, R805, ASK24, ASK85, ASK144, ASK381, and ASK612) from cycles-6 and 7 of ASK in 1971. The lines per se varied in oil concentration from 78 to 100 g kg^{-1}. UHO was developed from 81 S1 lines from cycle-21 of ASK. Lines selected for intermating were based on grain yield, oil concentration, and stalk-rot resistance of testcrosses to B73. Mean oil concentration of the lines was 140 g kg^{-1}.

Recurrent Selection Scheme

In each cycle, about 200 S0 plants of AE and UHO were crossed to B73. The 200 plants were inoculated with multiple stalk-rot diseases and about 150 S1 plants were saved. The 150 testcrosses were grown the next year and evaluated for grain yield and stand ability. A selection intensity of 10% was used each cycle and about 15 S1 lines with highest grain yield were intermated to form the next selection cycle. No selection was practiced for oil concentration. The two sets of testcrosses (AE and UHO) were grown in alternate years to reduce work load.

After six cycles were completed, remnant seeds from cycles-0, 3, and 6 of the two synthetics were planted for seed increase by hand pollination to produce six genotypes (i.e. AE C0, AE C3, AE C6, UHO C0, UHO C3, and UHO C6). Further, these six genotypes were testcrosses to B73, LH185, and LH202 inbreds (40 g kg^{-1} oil concentration) and obtained a total of 18 testcrosses. LH185 and LH202 inbreds were used as additional testers because of better agronomic superiority over the original B73 that was used during the six cycles of selection.

Selection Response Evaluation

Two types of field experiments were used to evaluate six cycles of selection in AE, UHO, and testcrosses of these genotypes to three inbreds (B73, LH185, and LH202). The trials were conducted separately at the Crop Sciences Research and Education Center, University of Illinois, Urbana, IL from 1999 to 2001. In the AE and UHO trials, six genotypes i.e. AE C0, AE C3, AE C6, UHO C0, UHO C3, and UHO C6 were evaluated using a RCB design with four replications at one location each year. The plot consisted of two rows 5.4 m in length and spaced 76 cm apart. All plots were over planted and thinned to a plant density of 68,000 plants ha^{-1}. In the testcross trial, 18 testcrosses were evaluated using the same design and treatment as per se trial except with five replications. Xenia effects for oil were controlled by selfing five plants per plot in both experiments. All plots were machine planted and harvested.

Data Collected

Data recorded on each plot were grain yield (Mg ha^{-1}) adjusted to 155 g kg^{-1} (15.5% grain moisture), and grain moisture content at harvest. Five self-pollinated ears were sampled from each plot and equal quantities of seeds from each ear were bulked to measure kernel oil, protein, and starch concentrations using Near Infra-red Transmission Spectroscopy as described by Itnyre (1992). Calorie production per hectare in testcrosses was estimated by multiplying oil, protein, and starch concentrations using the values of 9 kcal g^{-1} for oil, 4 kcal g^{-1} for protein, and 4 kcal g^{-1} for starch and then summing these values and multiplying by the grain yield per hectare as described by Weber (1987).

To measure changes in germ to endosperm ratio, two of five self-pollinated ears in each plot were sampled at about 300 g kg^{-1} grain moisture. Ten kernels from each of two ears (total 20 kernels) were dissected into germ and endosperm which included tip cap and pericarp. Germ oil concentration of 10 germs was determined using a Wide Line Nuclear Magnetic Resonance at Dupont (Alexander *et al.* 1967). The oil weight per germ was determined by multiplying germ oil concentration times dry weight per germ. Germ and endosperm dry weight were used to calculate the relative percentage of germ and endosperm to total dry weight of the two samples. Ten germs for each genotype were used to measure the average germ length and width.

Yield component measurements were taken to explain grain yield changes. In maize, total grain yield per plant is the product of six major components. Four of the six components, ear number per plant, kernel weight, row number per ear, and kernel number per row, are regarded as primary components of grain yield, since they cannot readily be further subdivided. Grain weight per ear and kernel number per ear are regarded as secondary components of grain yield, as they are the products of two or more primary components (Leng 1954). Yield components were measured from five open-pollinated ears sampled from each plot. Seeds from five open-pollinated ears in each plot were bulk and oven-dried. These bulk seeds were used to measure indirectly kernel size by dividing kernel dry weight in 30 cm^3 by the number of kernels. Changes in kernel weight were used as an indirect measure of changes in kernel size.

Data Analysis

All data expressed as plot means for statistical analysis of variance (ANOVA) using the generalized linear model procedures (SAS Institute Inc. 2000). Data for each year were analyzed separately and then combined analysis over years was performed as described by McIntosh (1983). A mixed model was used, with years as random effects and genotypes or testcrosses as fixed effects. Pearson correlation coefficients were estimated between all traits using testcross means over years.

RESULTS AND DISCUSSION

Significant effects between testcrosses were observed for grain yield from the combined analysis of variances over years (Table 1). Partitioning the testcross sources of variation into genotypes, testers, and genotypes x testers, resulted in significant effects between genotypes for grain yield, oil and starch concentrations. Significant effects between testers were observed for grain yield and the other four traits. Most of the traits did not show significant year x testcross interaction, including grain yield, suggesting testcrosses showed a consistent response ($P > 0.01$).

In the per se trials, significant differences were observed between years for all traits, except oil concentration, and germ and endosperm traits (data not shown). No significant difference was observed between genotype and grain yield. No significant year by genotype interaction was observed for all traits, suggesting the synthetics per se showed a consistent response.

Selection Response for Grain Yield

The testcross on grain yields (Table 2) increased from cycle-0 to cycle-3 and from cycle-3 to cycle-6 in four testcross groups namely AE x B73, AE x LH185,

Table 1. Analysis of variance for grain yield, oil, protein, and starch concentrations, and calorie production of Alexho Elite (AE) and Ultra High Oil (UHO) testcrosses selected for six cycles for increased grain yield, combined over 3 years (1999, 2000, and 2001).

Sources of variation	Degree of freedom	Mean squares				
		Grain yield	Oil concentration	Protein concentration	Starch concentration	Calorie production
Years	2	1423.97**	3458**	1574**	19544**	995**
Reps in years	12	2.09	84	118	749	38
Testcrosses	17	3.84**	503**	266**	1058**	50*
Genotypes (G)[1]	5	6.67**	1265**	22	1894*	101**
Testers (T)	2	10.24**	838**	1858**	3301**	95**
G x T	10	1.15	54	70	369*	15
Years x testcrosses	34	1.32	45	48	150	11
Error	204	0.96	31	69	159	12
Total	269	2.30	128	106	515	29

[1]AE and UHO each with cycles-0, 3, and 6.
*, ** = significant at the 0.05 and 0.01 probability levels, respectively.

Table 2. Grain yield and grain weight of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcrosses to three testers (B73, LH185, LH202), selected for increased grain yield for six cycles, averaged over three years (1999-2001).

Synthetic cycles	Grain yield (Mg ha^{-1})					Grain weight per plant (g)				
	B73	LH185	LH202	Mean	Per se	B73	LH185	LH202	Mean	Per se
AE C0	7.98	8.28	8.04	8.10	4.66	142	144	135	140	82.30
	(171)	(178)	(173)	(174)		(173)	(175)	(164)	(171)	
AE C3	8.15	9.21	8.19	8.51	4.50	152	155	149	152	84.30
	(181)	(205)	(182)	(189)		(181)	(185)	(177)	(181)	
AE C6	8.44	9.58	8.91	8.98	4.04	148	160	150	153	79.80
	(209)	(237)	(221)	(222)		(185)	(200)	(188)	(191)	
Mean	8.19	9.02	8.38	8.53	4.40	147.3	153	144.6	148.3	82.13
UHO C0	7.38	8.46	8.11	7.98	3.54	135	147	147	143	66.00
	(208)	(239)	(229)	(225)		(205)	(223)	(223)	(217)	
UHO C3	7.91	8.20	7.87	7.99	4.04	137	144	143	142	79.50
	(196)	(203)	(195)	(198)		(171)	(180)	(179)	(176)	
UHO C6	8.11	8.25	8.34	8.23	4.00	145	143	147	145	77.50
	(203)	(206)	(209)	(206)		(186)	(183)	(188)	(186)	
Mean	7.80	8.30	8.10	8.06	3.86	139	144.6	145	143	74.30
Grand mean	7.99	8.66	8.24	8.30	4.13	143	149	145	146	78.20
LSD 0.05		0.85		0.50	ns		13		8	ns
R[1] of AE	0.08	0.22	0.14	0.15	-0.10	1.00	2.67	2.50	2.17	-0.42
R of UHO	0.12	-0.04	0.04	0.04	0.08	1.67	-0.67	0.00	0.33	1.92

All numbers in the brackets mean relative performance of testcrosses over corresponding synthetic and cycle per se (%).
ns = not significant at the 0.05 probability level.
[1]R = selection response per cycle.

AE x LH202, and UHO x B73. In AE x B73 testcrosses, a 0.46 Mg ha^{-1} grain yield increase was observed over six cycles of selection or an increase of 0.08 Mg ha^{-1} (80 kg ha^{-1}) per cycle. The same trend also occurred in the testcrosses of UHO x B73, or a 0.73 Mg ha^{-1} increase over six cycles of selection or 0.12 Mg ha^{-1} per cycle. The consistent yield increase of testcrosses among cycles of selection in each synthetic suggested B73, as an original tester, discriminated well between half-sib families among cycles for both AE and UHO. The LH185 and LH202 testers consistently showed yield increase among cycles of selection for AE testcrosses but not for UHO.

The highest and significant increase in grain yield of 1.30 Mg ha^{-1} for six cycles was in the AE x LH185 testcrosses with selection response of 0.22 Mg ha^{-1} per cycle (Table 2). However, LH185 did not perform well when crossed to UHO, although still produced the highest average grain yield between the three testers crossed to UHO. Significant increase in grain yield of 0.87 Mg ha^{-1} was also observed in the AE x LH202 testcrosses. Selection responses for grain yield in AE x LH185 and AE x LH202 testcrosses were higher than those in UHO x LH185 and UHO x LH202.

AE x LH185 had a 0.72 Mg ha^{-1} or 9% greater grain yield than UHO x LH185 (9.02 vs. 8.30 Mg ha^{-1}). Averaged over cycles and testers, AE testcrosses had a 0.47 Mg ha^{-1} or 6% greater grain yield than UHO testcrosses (8.53 vs. 8.06 Mg ha^{-1}) which agrees with the synthetics per se result, where AE showed greater grain yield than UHO (Table 2). Averaged over three testers, AE testcrosses showed greater yield increase than those of UHO in six cycles of selection. Grain yield increases were 0.88 Mg ha^{-1} for AE testcrosses and 0.25 Mg ha^{-1} for UHO testcrosses, or with selection response of 0.15 and 0.04 Mg ha^{-1} per cycle for AE and UHO testcrosses, respectively.

Tester LH185 gave the highest yield of 8.66 Mg ha^{-1} compared to 7.99 and 8.24 Mg ha^{-1} for B73 and LH202, respectively. These results agree with the pedigree of the three inbreds. LH185 was derived from LH123 x Mo17, where Mo17 belongs to the Lancaster heterotic group. LH202 was derived from A662 x B73, suggesting that LH202 was closely related to B73 or both have the same heterotic group of Reid Yellow Dent (Mike Brayton Seeds 1995).

For cycles per se, there was a lower in grain yield of 0.62 Mg ha^{-1} in AE synthetic, while an increase of 0.46 Mg ha^{-1} was observed in UHO synthetic. No significant change was observed for grain yield in both AE and UHO from cycle-0 to cycle-6 (Table 1). These results suggest that six cycles of recurrent selection using B73 as an inbred tester for increased grain yield in AE and UHO did not affect yield performance of both AE and UHO synthetics per se. Garay *et al.* (1996) reported selection in the EZS1 population per se did not have any impact on performance of the testcrosses of EZS1 with tester EZ8, indicating alleles responsible for improvement in EZS1 were masked by alleles in the tester EZ8. For the same cycles or averaged over cycles, AE tended to have a greater grain yield than UHO (Table 2). Relative performance of testcrosses over corresponding cycle per se for grain yield ranged from 171 to 237% in AE testcrosses, and from 195 to 239% in UHO testcrosses or showed maximum heterosis of 137 and 139%, respectively (Table 2).

Correlated Responses to Yield Components

Grain weight per plant of testcrosses ranged from 135 to 160 g in AE testcrosses, and 135 to 147 g in UHO testcrosses (Table 2). In each of the two synthetics crossed to the three testers, all testcrosses showed an increase in grain weight per plant from cycle-0 to cycle-6, except UHO x LH185, which is probably the cause of grain yield reduction in the UHO x LH185 testcross. Significant increases in grain weight per plant from cycle-0 to cycle-6 were observed in AE x LH185 and AE x LH202 testcrosses.

The increase in grain weight per plant in AE x LH185 testcrosses was followed by an increase in kernel row number and kernel number per ear (Table 3), and kernel weight (Table 4). Significant changes in kernel number per ear were observed from cycle-0 to cycle-6 in AE x LH202 and UHO x B73 testcrosses of 10.5 and 10.0 kernels per ear per cycle, respectively (Table 3). A significant increase in kernel weight of 16 mg in six cycles or 2.7 mg per cycle occurred in AE x LH185 testcrosses. Averaged over testers, an increase of 10 mg in kernel weight was observed in AE testcrosses, but a slight reduction occurred in UHO testcrosses (Table 4). These results suggest single trait recurrent selection for increased grain yield produced a greater kernel size in AE testcrosses. Averaged over cycles, tester LH185 gave the highest kernel weight (302 mg) compared to B73 and LH202.

No significant changes from cycle-0 to cycle-6 in both AE and UHO synthetics per se were also observed for yield components. For the same cycles or averaged over cycles, AE tended to have a greater kernel row number per ear, kernel number per ear, kernel weight, and grain weight per plant than UHO.

Relative performance of testcrosses over corresponding cycle per se for grain weight per plant ranged from 164 to 200% in AE testcrosses, and from 171 to 223% in UHO testcrosses, or showed maximum heterosis of 100 and 123%, respectively, which were similar to those of grain yield.

Correlated Responses to Oil, Protein, and Starch Concentrations

No significant reduction in oil and protein concentrations was observed from cycle-0 to cycle-6 for both AE and UHO crossed to the three testers as a result of selection for increased grain yield. AE testcrosses had oil concentrations ranged from 64 g

Table 3. Kernel row number and kernel number per ear of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcrosses to three testers (B73, LH185, LH202), selected for increased grain yield for six cycles, averaged over three years (1999-2001).

Synthetic cycles	Kernel row number per ear					Kernel number per ear				
	B73	LH185	LH202	Mean	Per se	B73	LH185	LH202	Mean	Per se
AE C0	17.8	15.1	16.0	16.3	14.6	580	508	548	545	388
AE C3	17.4	15.4	16.5	16.4	14.9	554	533	581	556	364
AE C6	17.1	16.2	16.6	16.6	15.0	596	546	611	584	360
Mean	17.4	15.5	16.3	16.4	14.8	576	529	580	561	370
UHO C0	15.4	16.5	17.0	16.3	14.1	465	514	596	525	347
UHO C3	16.5	15.2	17.1	16.3	14.6	458	502	591	517	390
UHO C6	16.4	16.2	17.4	16.7	14.3	525	505	633	554	384
Mean	16.1	16.0	17.1	16.4	14.3	482	507	606	532	373
Grand mean	16.8	15.8	16.8	16.5	14.6	530	518	593	547	373
LSD 0.05		1.2			ns		56			ns
R[1] of AE	-0.12	0.18	0.10	0.05	0.07	2.7	6.3	10.5	6.5	-4.7
R of UHO	0.17	-0.05	0.07	0.07	0.03	10.0	-1.5	6.2	4.8	6.2

ns = not significant at the 0.05 probability level.
[1]R = selection response per cycle.

kg-1 (AE C3 x LH185) to 78 g kg-1 (AE C3 x B73), while UHO testcrosses had higher oil concentration than AE testcrosses, ranged from 79 g kg-1 in UHO C6 x LH185 to 89 g kg-1 in UHO C6 x LH202 (Table 4). AE testcrosses (having lower oil concentration) had higher average grain yield than UHO testcrosses. This could be the consequences of a lower oil level of AE, genetic background, or both as stated by Misevic and Alexander (1989).

Averaged over three testers, oil concentrations of AE testcrosses were 71 g kg-1 in cycle-0 and 73 g kg-1 in cycle-6, and for UHO testcrosses the oil levels were 83 g kg-1 in cycle-0 and 85 g kg-1 in cycle-6, suggesting selection for increased grain yield for six cycles using B73 as a tester did not reduce oil concentration in both AE and UHO testcrosses. Averaged over cycles and testers, UHO testcrosses had a 12 g kg-1 higher oil concentration than AE testcrosses (84 vs. 72 g kg-1). Between the three testers, testcrosses to B73 and LH202 produced similar oil concentrations of 80 g kg-1 which was 7 g kg-1 higher than the oil level of testcrosses to LH185.

A significant increase in starch concentration of 14 g kg-1 was observed in AE x LH185 testcrosses (646 vs. 632 g kg-1), which possibly the cause of significant increase in kernel weight in AE x LH185 testcrosses. AE testcrosses had higher starch concentration than UHO testcrosses (Table 5).

Table 4. Kernel weight and oil concentration of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcrosses to three testers (B73, LH185, LH202), selected for increased grain yield for six cycles, averaged over three years (1999-2001).

Synthetic cycles	Kernel weight (mg)					Oil concentration (g kg-1)				
	B73	LH185	LH202	Mean	Per se	B73	LH185	LH202	Mean	Per se
AE C0	284	296	267	282	266	73	66	73	71	87
AE C3	285	309	277	290	273	78	64	71	71	87
AE C6	290	312	275	292	272	75	68	75	73	89
Mean	476	305	273	288	270	75	66	73	72	87
UHO C0	281	303	270	285	246	84	82	83	83	128
UHO C3	285	295	271	284	256	83	81	87	84	124
UHO C6	283	297	262	281	255	87	79	89	85	134
Mean	283	298	267	283	252	84	80	86	84	128
Grand mean	285	302	270	286	261	80	73	80	78	108
LSD 0.05		13			ns		6			13
R[1] of AE	1.0	2.7	1.3	1.7	1.0	0.3	0.3	0.3	0.3	0.3
R of UHO	0.3	-1.0	-1.3	-0.7	1.8	0.5	-0.5	1.0	0.3	1.0

ns = not significant at the 0.05 probability level.
[1]R = selection response per cycle.

Table 5. Protein and starch concentrations of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcrosses to three testers (B73, LH185, LH202), selected for increased grain yield for six cycles, averaged over three years (1999-2001).

Synthetic cycles	Protein concentration (g kg-1)					Starch concentration (g kg-1)				
	B73	LH185	LH202	Mean	Per se	B73	LH185	LH202	Mean	Per se
AE C0	131	121	139	130	146	622	632	616	623	592
AE C3	132	122	135	130	137	611	639	621	624	602
AE C6	131	122	135	129	142	620	646	618	628	594
Mean	131	121	136	129	141	617	639	618	625	594
UHO C0	128	123	137	129	151	609	614	606	610	536
UHO C3	132	124	128	128	150	606	617	607	610	548
UHO C6	128	125	134	130	149	610	611	610	610	532
Mean	129	124	133	129	150	608	614	607	610	538
Grand mean	130	123	135	129	146	613	625	611	616	567
LSD 0.05		7			9		12			24
R[1] of AE							2.3			
R[1] of UHO							-0.5			

[1]R = selection response per cycle.

No significant changes from cycle-0 to cycle-6 in both AE and UHO were also observed for oil, protein, and starch concentrations (Tables 4 and 5). Averaged over cycles, UHO showed a 40 g kg^{-1} higher oil concentration (129 vs. 88 g kg^{-1}) but 57 g kg^{-1} lower starch concentration (539 vs. 596 g kg^{-1}) than AE.

Correlated Responses to Calorie Production and Grain Moisture

Significant increases in calorie production of 7.9 x 10^9 and 3.5 x 10^9 calories ha^{-1} were observed in AE x LH185 and AE x LH202 testcrosses, respectively. AE C6 x LH185 had the highest calories production of 36.7 x 10^9 calories ha^{-1} (Table 6). Average over testers and cycles, AE testcrosses had 2.2 x 10^9 calories ha^{-1} higher than UHO testcrosses (31.7 x 10^9 vs. 29.5 x 10^9 calories ha^{-1}). This finding agrees with the result reported by Dudley *et al*. (1977) indicating in these testcrosses the calorie production is influenced more by grain production than by energy concentration in the kernels.

Correlated Responses to Germ and Endosperm Traits

Six cycles of recurrent selection for increased grain yield did not significantly change the germ and endosperm traits in both AE and UHO testcrosses (Table 7). AE testcrosses tended to increase endosperm weight, but not for UHO testcrosses. Average over testers, there was a 22 mg increase in endosperm weight in AE testcrosses, but a decrease of 8 mg in UHO testcrosses after six cycles of selection. AE had greater endosperm weight (272 vs. 265 mg) but lower oil weight per germ (14.5 vs. 18.3) than UHO testcrosses. Averaged over cycles, tester LH185 showed the highest endosperm weight (288 mg) compared to 249 mg in B73 and 269 mg in LH202.

The significant differences between AE and UHO means for oil and starch concentrations were due to significant differences in germ and endosperm traits. Averaged over cycles, UHO had greater germ weight (57.8 vs. 42.6 mg) but lower endosperm weight (173

Table 6. Grain moisture and calorie production of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcrosses to three testers (B73, LH185, LH202), selected for increased grain yield for six cycles, averaged over three years (1999-2001).

Synthetic cycles	Grain moisture (g kg^{-1})					Calorie production (10^9 cal ha^{-1})				
	B73	LH185	LH202	Mean	Per se	B73	LH185	LH202	Mean	Per se
AE C0	191	166	172	176	167	29.2	28.8	29.6	29.2	-
AE C3	202	177	185	188	174	31.3	34.1	30.2	31.9	-
AE C6	199	164	179	181	166	32.0	36.7	33.1	33.9	-
Mean	197	169	178	181	169	30.8	33.3	30.9	31.7	
UHO C0	189	186	184	186	181	26.9	31.2	30.0	29.4	-
UHO C3	209	192	173	191	184	27.9	30.6	29.1	29.2	-
UHO C6	202	187	183	191	190	28.4	30.1	31.1	29.9	-
Mean	263	188	180	189	185	27.7	30.6	30.0	29.5	
Grand mean	230	178	179	185	177	29.3	31.9	30.5	30.5	
LSD 0.05		15			ns		3.2		2.4	

Table 7. Germ and endosperm traits of Alexho Elite (AE) and Ultra High Oil (UHO) maize synthetics per se and their testcross means, selected for increased grain yield for six cycles.

Synthetic cycles	Germ weight (mg)		Endosperm weight (mg)		Oil weight per germ (mg)	
	Testcross means[1]	Per se	Testcross means	Per se	Testcross means	Per se
AE C0	45.0	42.1	261	211	14.0	19.9
AE C6	47.5	43.0	283	203	15.0	21.3
Mean	46.2	42.6	272	207	14.5	20.6
UHO C0	54.0	58.9	269	180	18.1	26.4
UHO C6	52.0	56.6	261	166	18.6	27.0
Mean	53.0	57.8	265	173	18.3	26.7
Grand mean	49.6	50.2	268	190	16.4	23.6
LSD 0.05	9.0	8.5		28		ns

[1]Testcross means of AE and UHO over three testers (B73, LH185, and LH202).

vs. 207 mg) than AE. This is likely because 85% of oil concentration is located in the germ (Orthoefer and Sinram 1987).

Association Between Traits

Nonsignificant negative correlation (r = - 0.42) between grain weight per ear and oil concentration was observed in the 18 testcrosses (Table 8). Grain weight per ear showed significant positive correlations with starch concentration (r = 0.62**) and kernel weight (r = 0.47*). Kernel weight showed significant positive correlation with starch concentration (r = 0.67**), but negative correlations with oil concentration (r = - 0.52*) and protein concentration (r = - 0.85**). The negative association of oil concentration with grain weight per ear and kernel weight in this study agrees with those reported by Dudley *et al.* (1977), Willman *et al.* (1987), and Misevic and Alexander (1989). Significant negative associations were observed between grain weight per ear and ear height, suggesting high yield synthetic with low plant stature could be developed from AE and UHO testcrosses.

CONCLUSION

Six cycles of recurrent selection using an inbred tester B73 for increased grain yield was effective in increasing grain yields of AE testcrosses without decreasing both oil and protein concentrations as well as undesirable performance of both AE and UHO per se. AE testcrosses (having lower oil concentration) produced higher grain yield and greater selection response for grain yield than UHO testcrosses. LH185 was the best between the three testers for grain yield in AE and UHO testcrosses.

An increase in grain yield from cycle-0 to cycle-6 in most of the testcrosses was associated with increases in grain weight per ear, kernel weight, kernel number per ear, and starch concentration.

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Table 8. Phenotypic correlation coefficients among grain weight per ear, kernel chemical concentrations, and yield components of 18 testcrosses derived from six Alexho Elite and Ultra High Oil maize synthetics crossed to three inbreds.

Traits	Grain moisture	Oil concen-tration	Protein concen-tration	Starch concen-tration	Kernel weight	Kernel number per ear	Ear length	Ear diameter number	Kernel row
Grain weight per ear	-0.26	-0.42	-0.30	0.62**	0.47*	0.36	0.07	0.04	-0.13
Grain moisture		0.47*	0.23	-0.57*	-0.11	-0.38	0.08	0.61*	-0.32
Oil concentration			0.26	-0.86**	-0.52*	0.05	-0.14	0.19	0.34
Protein concentration				-0.51*	-0.85**	0.48*	-0.51*	-0.03	0.54*
Starch concentration					0.67**	-0.02	-0.21	-0.26	-0.37
Kernel weight						-0.54*	-0.45	0.26	-0.46
Kernel number per ear							0.31	-0.22	0.57*
Ear length								0.18	-0.16
Ear diameter									0.44

*, ** = significant at the 0.05 and 0.01 probability levels, respectively.

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