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Populations of Exotic × Locally Adapted Germplasm - A Potential Source of Inbred Lines for Superior Indigenous Maize Hybrids

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ABSTRACT

Experimental indigenous maize hybrids were evaluated in a series of three maize experiments during 2011, 2012 and 2013 to identify superior hybrids for commercial cultivation. Parental inbred lines of these hybrids were obtained from various indigenous populations, including a new improved maize population PSEV-3 which developed by the crossing of a locally adapted variety to an exotic hybrid obtained from CIMMYT and improved through S_1 progeny recurrent selection. Two popular commercial hybrids namely, Babar (Public sector hybrid) and one Pioneer hybrid i.e., P-3025 were included as check genotypes. Results revealed that experimental PESV-3 derived hybrids revealed better performance by comparing with three check hybrids for grain yield (11.35 vs. 8.13 t ha^{-1}, 10.67 vs. 9.60 t ha^{-1}, and 11.69 vs. 11.20 t ha^{-1}), thousand grain weight (372 vs. 338 g, 370 vs. 322 g, and 416 vs. 396 g), shelling % (87 vs. 86.2%, 86 vs. 85%, and 87 vs. 90%) and days to flowering (66.3 vs. 73.6 days, 64 vs. 67 days, and 69 vs. 68 days), respectively in three experiments. Three most superior hybrid combinations developed through exotic × locally adapted germplasm were found too much responsive and suggested their further testing through on-farm trials before releasing as commercial hybrids.

Keywords: Commercial hybrid; Exotic germplasm; Indigenous maize hybrid; Improved maize population; *Zea mays* L

1. Introduction

Maize (*Zea mays* L.) is the highest tonnage crop in the world, followed by paddy rice and wheat (FAO 2014). During 2014, maize was cultivated on an area of 177 million ha in the world with production of 967 million tons. In Pakistan, maize is the fourth largest grown crop after wheat, cotton, and rice. In Pakistan, during 2013-2014, maize was cultivated on 1.1685 million ha, and production was 4.9442 million tons with an average yield of 4.1 tons ha^{-1} (PBS 2015). In Khyber Pakhtunkhwa province of Pakistan, maize occupies the second position as a summer cereal, after wheat, in the crop husbandry (Khan et al 2004). Besides its use as staple food by the farming community, it is an important source of both green and dry fodder for livestock for much of the province, especially the mountainous areas (Khan et al 2003). A modest increase of 2% in the average yield ha^{-1} in Khyber Pakhtunkhwa province compared to 100% increase in the average yield of maize in Punjab province of Pakistan in the last 10 years, primarily due to use of maize hybrids especially single crosses, has been observed. In Khyber Pakhtunkhwa, normally open-pollinated maize varieties are being used which have low yield potential compared to hybrids. This yield gap between the average and the achievable potential in the Khyber Pakhtunkhwa province could be easily filled with the cultivation of single cross hybrids by the farmers on a commercial basis (Khan et al 2011). Farmers have gradually shifted towards hybrid maize from traditionally open-pollinated varieties (OPVs) as maize has increased production from 3750 to 10000 kg ha^{-1}. The corn crop is now highly lucrative for farmers as it has higher per hectare yield than other crops in the area (The Nation 2014).

The introgression of some useful genes from exotic maize germplasm into locally adapted germplasm is an effective way to broaden the genetic base of local maize germplasm and to extract new superior inbred lines for hybrid maize development (Kauffman et al 1982; Albrecht & Dudley 1987; Abadassi & Herve 2000; Fan et al 2008b). Most maize breeders, with experience of exotic germplasm, are of the opinion that inbred lines or hybrids are more promising source materials than populations with no history of inbreeding (Goodman 1992; 1999).

The primary reasons to use exotic germplasm are a) that increased genetic diversity provides a safeguard against unpredictable biological and environmental hazards (Goodman 1992; Michelini & Hallauer 1993), b) that exotic germplasm is a source of genes for specific traits including aflatoxin resistance, drought tolerance, and husk coverage (Albrecht & Dudley 1987; Betran et al 2006), and c) that exotic germplasm is a source of favorable alleles for increased yield and enhanced heterosis (Albrecht & Dudley 1987; Tallury & Goodman 1999).

Most of the plant breeders in the world agree that exotic germplasm is a source of desirable traits; however, several challenges limit their use. Tropical inbreds are poorly adapted to temperate environments expressing excessive lodging, poor cold tolerance, poor floral synchronization, disease susceptibility, late maturity, high grain moisture and slow dry down, barrenness in high plant densities, photoperiod response, tall stature, large tassel size, and high ear placement (Goodman et al 1990; Tallury & Goodman 1999; Lewis & Goodman 2003). The use of exotic germplasm is also limited by lack of information about as to how exotic germplasm combines with adapted germplasm and the resulting loss of heterotic patterns (Hallauer 1978; Echandi & Hallauer 1996). Moreover, close linkage of favorable alleles with unfavorable alleles is still another challenge for the breeders working with exotic germplasm (Echandi & Hallauer 1996).

To increase genetic diversity, breeders can use tropical and subtropical collections as a source of new genes (Echandi & Hallauer 1996; Goodman et al 2000). Germplasm from CIMMYT, OPVs and inbred lines derived from these populations, have shown to possess a vast genetic variation since these populations were a mixture of subtropical, tropical mid-altitude and highland maize populations and pools (Xia et al 2005) and appeared as the best sources of genetic diversification across the world (Fan et al 2002; Fan et al 2003a; Fan et al 2003b; Fan et al 2008a; Fan et al 2008b; Aguiar et al 2008; Nelson & Goodman 2008).

In general, using a range of germplasm sources seems to be necessary for sustaining long-term breeding progress in maize and for avoiding an increase in the susceptibility to stresses (Reif et al 2010). Exotic or adapted, but not improved, germplasm can be used to increase the genetic base of maize breeding germplasm (Romay et al 2011). The adapted, non-improved germplasm needs to be improved before it can be included in hybrid breeding programs because of its poor agronomic performance, particularly low yield and high lodging.

Therefore, the purpose of the present research was to improve the existing population(s) for use in the extraction of superior inbred lines for high yielding maize hybrids. Specific objectives of the study were to a) evaluate the experimental (indigenous) maize hybrids for grain yield and other agronomic traits, and b) identify superior hybrid combinations for further testing on farmer's fields before releasing for commercial cultivation.

2. Material and Methods

2.1. Germplasm improvement and inbred line development

A new breeding population, PSEV-3 (CHSW × Azam), was developed by crossing the exotic subtropical material from CIMMYT with an adapted local open pollinated maize variety in spring 1999 at the Cereal Crops Research Institute (CCRI), Pirsabak-Nowshera, Pakistan. Azam is a white kernel adapted open pollinated maize variety possessing temperate and subtropical germplasm for earliness, adaptability and grain yield. The CHSW was an experimental CIMMYT hybrid of subtropical origin having a white kernel, resistance to foliar and stalk rot diseases, stay-green and good resistance to lodging. The population was improved through two cycles of half-sib recurrent selection alternating with homogenization after each cycle through half sib recombination block. The objective was to incorporate the desirable traits of the hybrid into the adapted local variety. This population (PSEV-3) was then subjected to S_1 progeny intra-population recurrent selection for further improvement in grain yield and other agronomic traits for variety development and to extract inbred lines for development of superior maize hybrids. A number of inbred lines were derived from this population by using an early-generation testing program for inbred line development (Table 1). Selected S_1 lines were advanced to S_2 and subsequently to S_3 and S_4 generations through selfing procedure in the breeding nursery. Superior S_4 lines were selected and advanced to S_5 after replicated yield trial (data not shown). Superior S_5 lines were further advanced to S_6 through sibbing (Fehr et al 1987).

2.2. Evaluation trials

The plant material in the present study comprised of various hybrids (single crosses, double crosses, three-way crosses, and inbred-population crosses) among inbred lines derived from various source populations, including that developed from crossing exotic × adapted local germplasm, PSEV-3 (Table 1). PSEV-3 (ES), Jalal and Sarhad White (SW) were among the three cultivars used in the inbred-variety crosses. Jalal and Sarhad White have been developed from subtropical germplasm and are now under commercial cultivation in the area, whereas PSEV-3 (ES) is an experimental earlier maturing variety derived from PSEV-3. Two popular commercial hybrids well known to farmers and breeders, namely, Babar (public sector hybrid) and one Pioneer hybrid i.e., P-3025 were included as checks. These hybrids were evaluated in three separate preliminary yield trials during 2011, 2012 and 2013 in a randomized complete block design with four replications at COMSATS Abbottabad, Pakistan. A plot size of four rows each of 5 m long, and 20 and 75 cm spacing between plant to plant and row to row, respectively were used in each plot. Management, fertilization, pest and weed control were carried out according to local practices in the area.

2.3. Traits measurement and statistical analysis

Data were recorded for grain yield, 1000-grain weight, shelling percentage, plant population, cobs ha^{-1}, plant height, ear height and days to 50% silking. Data were analyzed using analysis of variance appropriate to the design, using MSTAT-C computer program (Steel et al 1997). Means for various traits among genotypes were compared using the least significant differences (LSD) test.

3. Results

Mean comparison indicated significant differences among 22 hybrids for various traits in the first experiment during 2011 (Table 2). Grain yield

Table 1- Inbred lines, source population and description of source population

Sample no	*Inbred line*	*Source population*	*Population description*
1	USDA-17	Not known	Not known
2	FRW-8	FRHW-22 (F2)-5	FRHW-22 (F2)-5, a single cross hybrid- used as a female parent of an indigenous commercial double cross hybrid, Babar
3	FRW-2	FRHW-20 (F2)-4	FRHW-20 (F2)-4, a single cross hybrid- used as a male parent of an indigenous commercial double cross hybrid, Babar
4	FRW-3	FRHW-22 (F2)-8	FRHW-22 (F2)-8, a single cross hybrid- used as a female parent of an indigenous commercial double cross hybrid, Babar
5	FRW-6	FRHW-22 (F2)-4-7	FRHW-22 (F2)-4-7, a single cross hybrid- used as a female parent of an indigenous commercial double cross hybrid, Babar
6	PK-9	FRHW-20 (F2)-4	FRHW-20 (F2)-4, a single cross hybrid- used as a male parent of an indigenous commercial double cross hybrid, Babar
7	PSEV-3-4-0-7	PSEV-3	PSEV-3, an improved population derived from crossing of subtropical exotic germplasm (CHSW) to an adapted local commercial variety Azam
8	PSEV-3-5-4-2-7-5-1	PSEV-3	PSEV-3, an improved population derived from crossing of subtropical exotic germplasm (CHSW) to an adapted local commercial variety Azam
9	PSEV-3-4-3-8-5-4	PSEV-3	PSEV-3, an improved population derived from crossing of subtropical exotic germplasm (CHSW) to an adapted local commercial variety Azam
10	PSEV-3-2-3-2-0-2-1	PSEV-3	PSEV-3, an improved population derived from crossing of subtropical exotic germplasm (CHSW) to an adapted local commercial variety Azam
11	SWAJ-4-9-2	Sarhad White	Sarhad White, an improved late maturing local commercial variety- derived from subtropical germplasm from CIMMYT.
12	SHS-2-17	Shaheen	Shaheen, an improved early maturing local commercial variety- derived from temperate germplasm.
13	SHS-2-19	Shaheen	-do-
14	SHS-2-26	Shaheen	-do-
15	SHS-2-62	Shaheen	-do-
16.	SHS-2-115	Shaheen	-do-
17	SHS-2-117	Shaheen	-do-
18	SHS-2-129	Shaheen	-do-
19	SHS-2-131	Shaheen	-do-
20	SHS-2-155	Shaheen	-do-
21	SHS-2-164	Shaheen	-do-
22	SHS-2-173	Shaheen	-do-
23	SHS-2-174	Shaheen	-do-
24	SHS-2-189	Shaheen	-do-

variations ranged from 3.38 t ha^{-1} for SW × USDA-17 (single cross hybrid) to 11.35 t ha^{-1} for (FRW-3 × FRW-6) × PSEV-3-4-0-7 (a modified single cross). FRW-3 × PSEV-3-4-0-7 (a single cross hybrid) was the second highest hybrid with a grain yield of 10.92 t ha^{-1}. Both these high yielding hybrids i.e., FRW-3 × PSEV-3-4-0-7 and (FRW-3 × FRW-6) × PSEV-3-4-0-7 possessed the highest shelling % of 87.0 and 87.9, 1000 grain weight of 368 g and 372 g, and a reasonable time to maturity of 66.3 and 68.3 days, respectively. Except for (FRW-3 × FRW-6) × SHS-2-26, with a grain yield of 9.20 t ha^{-1}, all other hybrids including the two commercial hybrids (Babar and P-3025) were found to have a grain yield and 1000-grain weight significantly lower compared to two experimental hybrids involving PSEV-3-4-0-7 as the male parent in the cross.

Table 2- Means of 21 experimental and three check maize hybrids for various traits during 2011

Hybrids	*Grain yield (t ha^{-1})*	*1000-grain weight (g)*	*Shell. (%)*	*Plant pop. ha^{-1} (000)*	*Cobs ha^{-1} (000)*	*Plant height (cm)*	*Ear height (cm)*	*50% silking (days)*
SW × USDA-17	3.38	301	82.1	69.3	50.4	229	100	61.5
SW × SHS-2-174	7.87	331	83.1	67.9	60.8	239	90	63.5
(FRW-2 × FRW-8) × SHS-2-129	7.73	314	85.1	62.4	58.8	245	115	64.6
SW × SHS-2-17	5.40	277	83.2	62.4	49.6	232	97	64.0
FRW-3 × PSEV-3-4-0-7	10.92	372	87.9	63.9	55.7	271	133	68.3
(FRW-3 × FRW-6) × PSEV-3-4-0-7	11.35	368	87.0	65.6	68.0	269	139	66.3
SHS-2-174 × FRW-2	5.59	358	86.5	30.2	30.7	250	103	66.0
(FRW-2 × FRW-8) × SHS-2-19	6.16	298	85.0	70.1	54.2	235	109	62.4
SHS-2-131 × PSEV-3(ES)	6.21	304	82.2	68.5	64.9	222	88	61.0
SW × SHS-2-62	4.03	298	85.8	48.6	38.9	202	68	59.6
SW × SHS-2-164	7.37	326	80.5	70.0	66.4	228	102	63.0
SHS-2-189 × SW	6.57	298	83.4	48.6	54.2	234	92	64.0
FRW-2 × SHS-2-19	3.97	304	84.8	45.5	26.6	222	99	61.3
SHS-2-73 × SW	4.90	324	84.0	42.5	39.3	217	78	56.3
(FRW-3 × FRW-6) × SHS-2-131	7.70	284	87.5	67.0	69.5	221	104	61.0
(FRW-3 × FRW-6) × SHS-2-26	9.20	349	84.5	70.0	66.4	231	110	61.6
(FRW-3 × FRW-6) × SHS-2-115	7.14	294	86.3	68.5	68.0	228	92	59.3
(FRW-3 × FRW-6) × SHS-2-174	5.50	332	86.9	76.2	57.3	201	85	66.0
SHS-2-155 × SW	4.58	247	84.8	40.9	43.5	214	95	62.0
SHS-2-174 × SW	6.83	298	85.2	62.4	54.7	244	96	63.6
(FRW-2 × FRW-8) × SHS-2-19	5.89	308	86.6	68.5	52.7	229	107	63.3
FRW-2 × FRW-8	8.17	300	84.8	63.9	54.2	237	110	71.6
Babar (check-1)	8.37	302	86.4	71.6	64.9	221	96	67.0
P-3025 (check-2)	8.13	338	86.4	54.7	67.3	251	108	73.6
$LSD_{0.05}$	3.08	45	2.32	10.7	17.5	23.1	24.8	3.96
CV (%)	26.37	8.76	1.67	14.6	22.3	5.98	14.5	3.75

During 2012, significant differences were observed among 10 hybrids after mean comparison for various traits in the second experiment (Table 3). Grain yield of hybrids ranged from as low as 8.20 t ha^{-1} for commercial hybrid (Babar) to as high as 10.67 t ha^{-1} for (FRW-3 × FRW-6) × PSEV-3-4-0-7. Again FRW-3 × PSEV-3-4-0-7 appeared as the second highest yielding cross in the trial with a grain yield of 10.63 t ha^{-1}. These two hybrids, having PSEV-3-4-0-7 as the male parent, were significantly different from all other hybrids including the commercial hybrids for grain yield and 1000-grain weight whereas no such differences could be seen for shelling %. However, these hybrids appeared to have a comparable number of days to mid silking with local commercial check, Babar (64.5 days) and significantly lower number of days to 50% silking (64.0 and 64.8 days for (FRW-3 × FRW-6) × PSEV-3-4-0-7 and FRW-3 × PSEV-3-4-0-7, respectively) compared to that of commercial exotic hybrid (P-3025) with 67.0 days.

During 2013, results revealed that significant differences were noted among 22 maize hybrids for all traits including grain yield in the third experiment (Table 4). Grain yield variation ranged from the lowest of 4.32 t ha^{-1} for FRW-6 × FRW-3 to the highest of 11.69 t ha^{-1} for (FRW-3 × FRW-6) × PSEV-3-4-0-7, whereas days to mid silking ranged from as lowest as 61 days for SHS-2-131-6 × FRW-2 to as highest as 75 days for PSEV-3-2-3-2-0-2-1 × FRW-2. Similar variations were also observed for other traits i.e., 1000-grain weight varied from 265 g (FRW-6 × FRW-3) to 416 g (FRW-3 × FRW-6) × PSEV-3-4-0-7, shelling % from the lowest of 79% (PSEV-3-2-3-2-0-2-1 × FRW-2) to the highest of 90% (P-3025) and plant height from 210 (FRW-6 × FRW-3) to 272 cm (PK-9 × PSEV-3-5-4-2-7-5-1). Two experimental hybrids i.e., (FRW-3 × FRW-6) × PSEV-3-4-0-7 (11.69 t ha^{-1}) and PSEV-3-5-4-2-7-5-1× FRW-2 (11.47 t ha^{-1}), had higher grain yield than both commercial check hybrids and were significantly different only from check-1 (Babar).

4. Discussion

On the average, 73% hybrids of those which had one parental inbred line derived from the PSEV-3 population in their pedigree were high yielding and significantly different from commercial check-1, while only 9% of the other hybrids had grain yield superiority over the local commercial check. A

Table 3- Means of the 10 experimental and two check maize hybrids for various traits during 2012

Hybrids	*Grain yield (t ha^{-1})*	*1000-grain weight (g)*	*Shell. (%)*	*Plant pop. ha^{-1} (000)*	*Cobs ha^{-1} (000)*	*Plant height (cm)*	*Ear height (cm)*	*50% Silking (days)*
Jalal × FRW-2	9.57	326	84	73.9	67.9	260	124	66.0
PK-9 × Jalal	9.60	325	82	65.6	63.3	270	123	70.0
FRW-3 × PSEV-3-4-0-7	10.63	370	86	70.9	72.3	247	110	64.8
SHS-2-26 × FRW-2	8.93	326	84	64.6	61.6	239	114	61.0
PSEV-3(ES) × FRW-2	8.95	320	83	45.3	42.6	271	123	68.2
SHS-2-173-6 × PSEV-3(ES)	8.14	332	85	72.9	66.6	230	113	58.8
SHS-2-117-3 × PSEV-3(ES)	9.19	315	85	71.6	72.9	248	100	59.2
(FRW-3 × FRW-6) × PSEV-3-4-0-7	10.67	356	85	71.3	70.6	258	128	64.0
SHS-2-131-6 × FRW-2	9.40	337	82	75.3	74.6	245	111	61.0
SHS-2-174-5 × PSEV-3(ES)	9.16	319	84	69.9	65.6	251	102	64.8
Babar (Check-1)	8.20	300	84	64.6	60.6	235	104	64.5
P-3025 (Check-2)	9.60	322	85	73.3	68.6	265	115	67.0
$LSD_{0.05}$	1.02	22.1	1.4	7.3	8.8	19.1	14.57	1.6
CV (%)	7.9	4.7	1.2	7.4	9.4	5.3	8.9	1.8

Table 4- Means of 22 experimental and two check maize hybrids for various traits during 2013

Hybrids	*Grain yield (t ha^{-1})*	*1000-grain weight (g)*	*Shell. (%)*	*Plant pop. ha^{-1} (000)*	*Cobs ha^{-1}(000)*	*Plant height (cm)*	*Ear height (cm)*	*50% Silking (days)*
PSEV-3-5-4-2-7-5-1 × FRW-2	11.47	324	84	72.9	73.9	280	132	71
SHS-2-131-6 × FRW-2	7.72	319	83	61.4	58.3	228	85	61
FRW-6 × PSEV-3-4-0-7	9.31	380	86	69.7	63.5	247	108	66
FRW-3 × PSEV-3-4-0-7	9.33	387	86	70.8	63.5	218	120	68
FRW-6 × FRW-3	4.32	265	84	61.4	53.1	210	110	67
SHS-26-2 × FRW-2	7.83	334	84	68.7	64.5	220	102	65
SHS2-131-6 × PSEV-3-5-4-2-7-5-1	8.24	365	86	71.8	69.7	233	96	63
SHS-2-131-6 × PSEV-3-4-0-7	8.40	382	83	55.2	58.3	265	113	62
RMW8 × FRW-2	7.31	304	83	70.8	53.1	247	102	69
SHS-2-131-6 × FRW-2	8.91	317	83	69.7	69.7	245	112	59
PSEV-3-4-3-8-5-4 × FRW-2	10.41	376	85	72.9	64.5	248	107	70
PK9 × RMW8	6.23	336	81	71.8	55.2	251	105	73
PK-9 × PSEV-3-5-4-2-7-5-1	9.24	340	84	60.4	57.2	272	112	72
PSEV-3-4-3-8-2-5-4 × FRW-2	8.67	344	84	68.7	62.5	241	95	73
PSEV-3-2-3-2-0-2-1 × FRW-2	9.83	386	79	75.0	65.6	257	92	75
PK-9 × SWAJ-4-9-2	7.26	301	84	66.6	58.3	236	102	71
SWAJ-4-9-2 × FRW-2	7.63	343	84	60.4	54.1	237	112	69
PK-9 × PSEV-3-4-0-7	10.87	363	85	67.7	67.7	268	117	73
(FRW-3 × FRW-6) × PSEV3-45-4-3-7	6.75	352	85	65.6	44.7	247	96	70
(FRW3 × FRW6) × PSEV-3-5-4-2-7-5-1	7.82	349	86	72.9	54.1	255	108	70
(FRW-3 × FRW-6) × SWAJ-4-9-2	6.14	267	84	70.8	67.7	243	100	66
(FRW-3 × FRW-6) × PSEV-3-4-0-7	11.69	416	87	70.8	67.7	271	130	69
Babar (Check-1)	7.25	300	84	67.7	64.5	231	105	66
P-3025 (Check-2)	11.02	396	90	66.6	64.5	270	115	68
$LSD_{0.05}$	1.59	28.43	1.7	7.6	10.2	27.0	20.61	2.7
CV (%)	14.1	5.9	1.5	8.0	11.8	7.8	13.6	2.7

similar trend of an increased superiority of hybrids with lines from the PSEV-3 was also seen for 1000-grain weight and shelling percentage where 100% of these hybrids had significantly higher 1000-grain weight compared to local check-1 as against only 5% for the other hybrids not having such lines in their pedigrees. Majority of the high yielding experimental hybrids having parental lines from PSEV-3 and also the Pioneer check hybrid (P-3025) were generally taller in stature with high ear placement and more days to flowering compared to other experimental hybrids and local commercial check hybrid (Babar). Present results corroborate the findings of previous studies on the use of exotic germplasm as a source of favorable alleles for increased grain yield and other desirable traits in maize breeding programs (Hallauer & Carena 2009).

The higher grain yield and grain yield components (such as 1000-grain weight and shelling %) of our hybrids with one parental inbred line derived from PSEV-3, especially (FRW-3 × FRW-6) × PSEV-3-4-0-7, PSEV-3-5-4-2-7-5-1 × FRW-2 and FRW-3 × PSEV-3-4-0-7, which could be attributed to favorable alleles for increased grain yield and heterosis (Albrecht & Dudley 1987; Tallury & Goodman 1999), and might have accumulated in the elite parental lines during pre-breeding component of the hybrid development (Carena 2005; Carena et al 2009).

The genetic diversity of PSEV-3 (CHSW × Azam) has probably allowed the extraction of a number of elite inbred lines for high grain yield and other desirable traits since germplasm from CIMMYT possess a vast genetic variation (Xia et al 2005) and found as the best sources of genetic diversification across the world (Fan et al 2002; Fan et al 2003a; Fan et al 2003b; Fan et al 2008a; Fan et al 2008b; Aguiar et al 2008; Nelson & Goodman 2008). The higher shelling percentage for the experimental hybrids with higher grain yield could be the result of a positive association between the two traits in the selection for high grain yield during inbred line development (Kadubiee & Kurianta 2004; Rafique et al 2004). Moreover, tall stature, high ear placement and late flowering of these hybrids appeared to be due to close linkage of favorable alleles with unfavorable alleles for such traits while working with exotic germplasm (Echandi & Hallauer 1996).

5. Conclusions

Results of the present study suggested that exotic maize germplasm from CIMMYT has been a useful source of many desirable traits including grain yield for incorporation into locally adapted germplasm. The improved population derived from such crosses led to the development of many elite inbred lines for use in the development of superior indigenous maize hybrids. Two single crosses, (FRW-3 × PSEV-3-4-0-7) and PSEV-3-5-4-2-7-5-1 × FRW-2, and one modified single cross (FRW-3 × FRW-6) × PSEV-3-4-0-7 appeared as the potential candidates for release as commercial hybrids, after evaluation on farmers' field.

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