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Heterotic Effect, Combining Ability and Significance of Synthetics over Line Cultivars in Faba Bean (*Vicia faba* L.) Grown under Semi-Arid Zones

Seif M. Gasim[1*], Alam E. Mohamed[2]

[1]Department of Agronomy, Faculty of Agriculture, University of Khartoum, Shambat, Sudan
[2]Department of Agronomy, Faculty of Agriculture, University of Zalingei, Zalingei, Sudan
Email: *seifm1963@gmail.com

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Abstract

The aim of this study was to investigate the amount of heterosis and performance of faba bean synthetic cultivars compared to line cultivars under semi-arid conditions. Five inbred lines in at least S_6 generation were developed and used to develop F_1s hybrid (in all possible combination excluding reciprocal), lines mixtures (Syn-0) and synthetic generations of Syn-1. Evaluation of the entries showed the lines to have high general and specific combining ability, high yield and high average degree of cross-fertilization (0.36); hetrosis relative to mid-parent for yield was 67%. Lines mixture from four inbred lines (Hudeiba/93, Bassabier, Ed-Damar and Shabah) gave the highest yield of 3.40 t/ha for Syn-0 and 3.96 t/ha for Syn-1. Compared to the average yield t/ha of the pure stand of the four lines (3.11 t/ha), the increase in yield of was 9% in sy-0 and 27% in Syn-1. Compared to the individual yield t/ha of the pure stand of the lines, the performance of Syn-0 surpassed that of the individual pure stands of the linesby 14% for Hudiaba/93 and Bassabier and 4% for Ed-Damar and 7% for Shabah, whereas the increase in performance of Syn-1 compared to pure stand of the lines was 32%, 25% and 21%, respectively. The results confirm the previous knowledge on yield increase with successive syn-generations in faba bean due to the effects of heterogeneity and heterozygosity. Such results could be used as a base for an effective breeding program for improvement of yield of faba bean grown under the semi-arid zones.

Keywords

Hetrosis, Synthetics, Faba Bean, Yield, Arid-Zone

1. Introduction

Faba bean is the most important food legume crop in North (Morocco, Egypt and Sudan) and East (Ethiopia) Africa. It contributes to the main human nutrition, supplying high quality protein crucial for a balance diet of millions of people who cannot afford meat as a source of protein. In addition, faba bean has been shown to increase soil fertility through biological N_2-fixation that can be used by the succeeding cereal crops and to break the cycle of biotic stresses [1]. The crop is grown under irrigated condition in Egypt and Sudan and under rain-fed in Morocco and Ethiopia. However, in Sudan (semi-arid zone), despite their importance as highly nutritious food stuffs, the productivity of crop is instable and far below its potential. Climate change, where the weather is becoming hotter and the season is shorter at the traditional production areas in the north, is among the most important constrains of the low productivity in Sudan [2].

To produce stable and high yield in faba bean, synthetic cultivars were recommended [3] as the commercial production of hybrid cultivars is not yet feasible due to the insufficient stability of the existing male sterility system [4]. Such cultivars were found to use part of the heterosis present in faba bean plant (75% as reported by [5] [6]) as well as their ability to adapt environmental variation, [3]. Although synthetic cultivars are less productive than heterotic hybrids, their main advantage is that the heterosis does not diminish significantly in F_2 [7]. Such variety is developed by selecting superior inbred lines having high combining ability and high heterosis [8] [9]. The objective of the present study was to assess the amount of heterosis in Sudanese faba bean as pre-requisite for production synthetic cultivars.

2. Material and Methods

2.1. Genetic Material and Field Experiment

Five inbred lines (in at least S6 generation) developed via single seed decent from the five locally grown faba bean cultivars in Sudan (Selaim, Hudeiba/93, Ed-Damar, Bassabier, and Shabah), representing a wide range of genetic variability in their agronomic traits (plant height, number of pods/plant, 100 seed weight, and yield), were used to fulfill the objectives of the present study. These lines were sown in isolated cages for multiplication (by hand tripping) and for cross purposes by hand in all possible combinations (in diallel cross excluding reciprocals) to produce F_1 seeds.

Three experiments were carried out at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum, Shambat (latitude 15˚40'N; longitude 32˚32'E, and altitude 380 meter above sea level). The site is located in the semi-arid zone; the soil is alkaline (pH 8.0); rainfall is about 150 mm per annum and with maximum temperature of about 42˚C in summer and around 21˚C in winter [10].

In experiment I, the seeds of the lines (parents) and F_1s were grown in seasons

2014/2015-2015/2016 to test the lines for general (GCA) and specific (SCA) coming ability.

In experiment II, the lines were evaluated in seasons 2014/2015-2015/2016 for the degree of cross-fertilization as described by Link [11] using the black hilum color as morphological marker. On average, from each entry 192 progeny were screened by year.

In experiment III, an equal number of seeds (25 seeds) from each of the five inbred lines [Hudeiba/93 (L_1), Ed-Damar (L_2), Shabah (L_3), Bassabeir (L_4) and Selaim (L_5)] were blended in all possible combination. Accordingly, sixteen blends/mixtures (M1 to M16) were developed. The line blends (one from all lines, five blends from four lines and ten blends from three lines) called Syn-0, were grown in season 2014/2015 under open pollination in spatial isolation to produce Syn-1seed. The seed of the lines blend (Syn-0) and that of Syn-1 were grown in season 2015/2016 and evaluated for yield and yield components.

Complete randomized block design with three replicates was used to execute the experiments. The gross plot size in the two experiments was 6.3 m^2 consisting of 3 ridges each 3 m in length and 70 cm apart. One seed was planted per hole with the spacing of 10 cm along the ridge. The experimental plots were irrigated every 14 days and weeded three times using hand hoe. The experiment was carried out in the presence of pollinators; here honeybee (*Apis mellifera* sp.) was introduced in the field of the experimental area.

2.2. Data Collection and Analysis

Data were collected from the parameters of: 1) days to flowering, determined when 50% of the plants of each entry open the first flower, 2) Plant height measured in cm at the end of the flowering period, 3) Number of pods per plant, 4) 100-seed weight (g), and 5) seed yield t/ha. The data were subjected to analysis of variance (ANOVA) according to the method described for the randomized complete block design (RCBD). The computer program SAS-1997version 9.0 was used for the analysis of variance.

The heterotic effects of F_1 crosses were estimated as a percentage over mid parent [12] as follows:

$$\text{Relative heterosis (RH) (\%)} = \frac{F_1 - \text{Midparent}}{\text{Midparent}} \times 100$$

Data for general combining ability (GCA) and specific combing ability (SCA) were analyzed as described by [13] for method 2 model I (all possible combination excluding reciprocal) as follows:

$$Y_{ij} = \mu + GCA_i + GCA_j + SCA_{ij} + e_{ijkl}$$

where:

Y_{ij} = Observation of *i*th parent in the *j*th block;

μ = population mean;

GCA_i = general combining ability (g.c.a) effect of the *i*th parent;

GCA_j = general combining ability (g.c.a) effect of the *j*th parent;

SCA_{ij} = specific combined effect (s.c.a) of two parents;

e_{ijkl} = experimental error.

The standard error required for testing the significance of general combining ability effects of the parents (p) and differences of GCA effects were obtained as:

$$S.E._{\hat{g}i} = \left(\frac{(P-1)}{p(p+2)}\sigma_e^2\right)^{1/2}$$

$$\text{and } S.E._{(\hat{g}i - \hat{g}j)} = \left(\frac{2}{p+2}\sigma_e^2\right)^{1/2}$$

Three errors required for testing the significance of specific combining ability effect of the parents (p) and differences of SCA effects were estimated as:

$$S.E._{\hat{s}ij} = \left(\frac{P^2+P+2}{(p+1)(p+2)}\sigma_e^2\right)^{1/2}$$

$$S.E._{(\hat{s}ij - \hat{s}ik)} = \left(\frac{2(P+1)}{(p+2)}\sigma_e^2\right)^{1/2}$$

$$\text{and } S.E._{(\hat{s}ij - \hat{s}kl)} = \left(\frac{2P}{p+2}\sigma_e^2\right)^{1/2}$$

3. Results

3.1. Variation and Mean Performance of the Entries

Mean squares from the analysis of variance for the studied traits in the 15 entries (parental lines and their F_1s) revealed highly significant differences, except for number of days to 50% flowering which exhibited non-significant differences (data not shown). Comparing the crosses performance with their corresponding parental lines, none of the lines exceeded hybrid performance in any of the studied traits (Table 1). For the lines, plant height was in the range from 74.40 cm for Hudeiba/93 to 70.00 cm for Seliam with an average of 72.50 cm. The performance of the F_1s, plant height ranged from 88.70 cm (Hudeiba/93 × Shaba) to 76.00 cm (Bassabier × Selaim) with an average of 81.50 cm. Number of pods per plant in the lines was in the range from 18.37 registered by Seliam to 27.00 in Bassabier and averaged to 23.20. In F_1s, the cross of L2 × L4 gave the highest number of pod per plant and cross L3 × L5 the lowest one. Although the line Shabah had the highest 100-seedweight (71.40g) and yield (3.17 t/ha) compared the other lines, the cross of Ed-Damar × Bassabier gave the highest number of pods/plant and yield (5.60 t/ha).

3.2. Combining Ability

Mean squares from the analysis of variance for GCA and SCA for the studied traits are presented in Table 2. The results indicated that the effect of general combining ability (GCA) for parental lines and specific combining ability (SCA) for crosses among the lines were highly significant ($p \le 0.01$) for all of the studied traits; the GCA was greater than SCA. Among the lines, Bassabier exhibited the highest positive GCA for number of pods per plant (1.29) and yield t/ha (0.08) (**Table 3**). Line Hudeiba/93 gave the highest positive GCA of 0.94 for plant height; Shabah line exhibited the highest (0.51) positive GCA for 100-seed weight, but the highest (−1.64) negative GCA for number of pods per plant. On the other hand, Selaim exhibited the highest (−0.19) negative GCA for yield t/ha.

For SCA, the magnitude of the crosses varied for the different traits e.g. the cross of Ed-Damar × Bassabier ($L_2 \times L_4$) showed the largest (33.52 cm) positive SCA effect for plant height and number of pods per plant (26.42); the cross of Shabah × Selaim ($L_3 \times L_5$) exhibited the largest (26.02) positive SCA effect for 100-seed weight (**Table 4**). Moreover, Hudeiba × Ed-Damar ($L_1 \times L_2$), Ed-Damar × Shabah ($L_2 \times L_3$) and Shabah × Bassabier ($L_3 \times L_4$) showed the highest (2.00) positive SCA effect for yield t/ha.

Table 1. Mean performance of yield and yield traits in fifteen faba bean entries.

Entry/trait	Days to flowering	Plant height (cm)	Pods/plant	100-seed weight (g)	yield (t/ha)
Hudeiba/93 (L1)	45.30	74.40	25.13	55.80	2.99
Ed-Damar (L2)	45.00	72.50	24.90	57.63	3.17
Shabah (L3)	45.00	73.00	20.60	71.40	3.27
Bassabeir (L4)	45.30	72.60	27.00	55.43	2.99
Selaim (L5)	44.30	70.00	18.37	67.30	2.96
Mean	44.98	72.50	23.20	61.51	3.07
L1 × L2 (F_1-1)	45.30	84.73	42.00	68.77	5.10
L1 × L3 (F_1-2	44.70	88.70	37.00	68.90	5.20
L1 × L4 (F_1-3)	45.00	85.16	39.00	68.50	5.11
L1 × L5 (F_1-4)	45.70	79.23	35.00	69.30	4.90
L2 × L3 (F_1-5)	45.30	80.00	37.00	71.97	5.20
L2 × L4 (F_1-6)	46.00	83.20	49.00	69.13	5.60
L2 × L5 (F_1-7)	45.70	81.40	36.00	70.37	5.00
L3 × L4 (F_1-8)	45.70	77.80	37.00	69.00	5.23
L3 × L5 (F_1-9)	45.30	78.30	33.00	73.60	5.25
L4 × L5 (F_1-10)	45.30	76.00	35.00	70.80	4.70
Mean	45.40	81.50	38.00	70.03	5.14
Gran mean	45.25	76.62	31.6	66.90	4.10
C.V	3.02	4.13	3.09	1.94	8.01
$LSD_{0.05}$	-	2.61	0.94	1.24	0.34

Table 2. Mean squares from the analysis of variance for general (GCA), specific (SCA) combining ability and error for yield and yield components in faba bean genotypes.

Source of variation	Degree of freedom	Plant height (cm)	Pods/plant	100-seed weight (g)	Yield (t/ha)
GCA	4	4820.83**	1034.87**	3501.66**	21.61**
SCA	10	338.88**	112.99**	235.90**	1.61**
Error	18	5.719	0.495	0.261	0.098

** = significant difference at 0.01.

Table 3. Estimation of general combining ability effect of five faba bean inbred lines for yield and yield components.

Line/trait	Plant height (cm)	Pods/plant	100-seed weight (g)	Yield t/ha
Hudeiba/93 (L1)	0.94	0.77	−0.41	0.02
Ed-Damar (L2)	0.29	0.52	0.14	0.05
Shabah (L3)	−0.28	−1.64	0.51	0.05
Bassabeir (L4)	0.12	1.29	−0.62	0.08
Selaim (L5)	−0.06	−0.94	0.39	−0.19
$S.E._{\hat{g}i}$	0.81	0.36	0.17	0.11
$S.E._{(\hat{g}i - \hat{g}j)}$	1.28	0.57	0.27	0.17

** = significant difference at 0.01.

Table 4. Estimation of specific combining ability effect of F_1-hybrids for yield and yield components in faba bean.

Cross/trait	Plant height (cm)	Pods/plant	100-seed weight (g)	Yield t/ha
L1 × L2	32.17	13.66	22.73	2.04
L1 × L3	28.58	12.96	23.59	1.87
L1 × L4	22.46	6.89	23.26	1.87
L1 × L5	30.08	20.32	22.11	1.64
L2 × L3	22.20	7.18	23.31	2.12
L2 × L4	33.52	26.42	23.11	1.72
L2 × L5	22.81	5.55	24.76	1.65
L3 × L4	25.63	12.77	22.44	2.13
L3 × L5	27.98	11.27	26.02	1.40
L4 × L5	28.41	9.84	22.05	1.90
$S.E._{\hat{s}ij}$	14.6	0.49	3.10	1.91
$S.E._{(\hat{s}ij - \hat{s}ik)}$	2.39	0.7	0.51	0.31
$S.E._{(\hat{s}ij - \hat{s}ik)}$	1.95	0.57	0.41	0.26

** = significant difference at 0.01.

3.3. Effects of Heterosis

Values of heterosis percentage relative to mid parents for the studied traits are presented in Table 5. The mean values were ranged from 10.50 for 100-seed weight to 67% for yield t/ha. Heterosis in plant height was in the range from 6% to 21.2% with an average of 12%. The highest plant height heterosis of 21.2% was given by the cross $L_1 \times L_3$ followed by the crosses of $L_1 \times L_2$ (17%), L1 × L_4 (16.15%) and $L_2 \times L_4$ (15%). Number of pods per plant exhibited heterosis values ranged from 50% ($L_1 \times L_4$) to 89% ($L_2 \times L_4$) with an average of 64%. Six crosses ($L_1 \times L_2$, $L_1 \times L_3$, $L_1 \times L_5$, $L_2 \times L_3$, $L_2 \times L_5$ and $L_3 \times L_5$) showed values of heterosis ranged from 61% to 69.23% and the crosses of $L_4 \times L_5$ and $L_3 \times L_4$ registered heterosis values of 54% and 55.5%, respectively. For100-seed weight, heterosis was in the range from 4.25% ($L_3 \times L_5$) to 23.2% ($L_1 \times L_4$) with an average of 10.5%. Heterosis for yield t/ha was in the range from 58% ($L_4 \times L_5$) to 82% ($L_2 \times L_4$) with an average of 67%. One cross ($L_1 \times L_5$) gave a heterosis of 72%, the remainder of the crosses showed a heterosis values ranged from 60% to 68% (Table 5).

3.4. Degree of Cross-Fertilization

Table 6 shows the mean, range and mean sum of squares for the degree of cross-fertilization of the five lines. There was significant ($p < 0.01$) variation among the inbred lines for the degree of cross-fertilization. Amongst their progenies a total of 692 individuals were white and 266 were black. The degree of cross-fertilization was in the range from 28.1% (Shabah) to 46.9% (Ed-Damar) with an average of 36%.

Table 5. Heterosis percentage relative to mid parents for yield and yield traits in faba bean.

Cross/trait	Plant height (cm) PH	Pods/plant	100-seed weight (g)	Yield t/ha
L1 × L2	16.15	67.90	21.24	65.58
L1 × L3	21.20	61.82	5.30	66.13
L1 × L4	17.00	50.00	23.20	67.22
L1 × L5	9.74	61.00	7.70	72.00
L2 × L3	9.97	62.64	7.45	61.50
L2 × L4	15.00	89.00	12.61	82.00
L2 × L5	13.50	66.40	7.90	60.00
L3 × L4	6.87	55.50	5.60	67.09
L3 × L5	8.75	69.40	4.25	68.27
L4 × L5	6.00	54.29	9.45	58.00
Mean	12.33	64.00	10.50	67.00

Table 6. Mean, range and mean squares from the analysis of variance the degree of cross-fertilization in five faba bean lines.

Lines	Degree of cross-fertilization
Mean	36.0 ± 7.8
Range	28.1 - 46.9
LSD	3.9
C.V	10.4
Mean squares	169.64**

**Significance at 0.01.

3.5. Synthetic Performance

Mean squares from the analysis of variance (Table 7) showed highly significant differences ($p \leq 0.01$) among the entries (lines blends in Syn-0 and Syn-1) for the studied traits. Generally, the increase in mean performance of lines blends for the studied traits in Syn-1 relative to Syn-0 was 24% for plant height, 13% for number of pods per plants and yield (t/ha); however, no significant increase in 100-seed weight of Syn-1 compared to Syn-0 was observed. For the performance of the lines blend, the tallest plant height was recorded by M8 in Syn-0 (76.6 cm) and M13 (92.9 cm) in Syn-1. In Syn-0, M3, M7 and M15 gave the highest number of pods per plant (25), whereas M2 and M13 registered the highest number of pods per plant (29) in Syn-1. M2 gave the highest yield of 3.4 t/ha for Syn-0 and 3.96 t/ha for Syn-1. On the other hand, the lowest yield of 2.13 t/ha and 2.39 t//ha was given by M11 in Syn-0and Syn-1, respectively (Table 6). The blend M2 was formed from four lines, namely Hudieba/93, Ed-Damar, Shabah, and Bassabier. The increase in performance of the four lines in Syn-1 compared to Syn-0 was 13% for plant height and number of pods per plant and 14% for yield t/ha. Compared to the average yield t/ha of the pure stand of the lines (3.07), the increase in yield of M2 was 11% in sy-0 and 29% in Syn-1. Compared with individual yield t/ha of the pure stand of the lines, 2.99 t/ha for Hudeiba/93 and Bassabier, 3.17 for Ed-Damar, 3.27 t/ha for Shabah and 2.96 t/ha for Selaim, (Table 1), the performance of Syn-0 in M2 surpassed the yield of pure stands of Hudeiba/93 and Bassabier by 14%, Ed-Damar by 7%, Shabah by 4%, and Selaim by 15%. For Syn-1, and as a result of increasing heterozygosity, the yield increase in M2 compared with the corresponding yield of the lines grown in pure stands was 32% of Hudeiba/93 and Bassabier, 25% of Ed-Damar yield, and 21% of Shabah yield and 34% of Selaim yield.

4. Discussion

4.1. Variability and Mean Performance of the Entries

To improve yield potentials of a crop, in breeding program, it is important to create new combinations of genes to produce genotype with trait performance that is superior to current genotypes at the target environment [14]. In the present study, the highly significant variations among the parental lines and their possible $F1$-hybrids for the studied traits provide evidence for the presence

Table 7. Mean performance of yield and yield traits in sixteen blends for five faba bean genotypes in Syn-0 and Syn-1 generation.

blend/trait	Plant height (cm)		pods/plant		100-seed weight (g)		Yield t/ha	
	SYN-0	Syn-1	Syn-0	Syn-1	Syn-0	Syn-1	Syn-0	Syn-1
M1	70.40	89.2	22	26	50.60	50.60	2.59	3.27
M2	72.60	82.10	24	29	52.20	55.20	3.40	3.96
M3	70.90	83.90	25	27	57.80	57.90	2.73	3.01
M4	70.80	82.20	23	25	50.00	50.10	2.64	2.94
M5	69.50	86.30	24	28	53.10	53.10	2.64	3.22
M6	69.80	85.30	24	26	51.60	51.70	2.75	3.04
M7	69.00	89.10	25	28	53.90	53.90	2.82	3.22
M8	76.60	88.10	24	26	47.20	47.20	2.82	2.92
M9	65.50	80.50	23	26	49.90	50.80	2.88	2.95
M10	70.70	90.50	24	26	55.20	58.50	2.63	2.84
M11	63.90	85.20	21	24	51.50	52.80	2.13	2.39
M12	66.60	91.80	23	26	52.90	53.90	2.42	3.10
M13	69.20	92.90	22	29	57.40	57.40	2.66	2.96
M14	69.80	89.90	23	27	55.50	58.90	2.63	2.91
M15	73.00	83.60	25	26	46.60	46.60	2.26	2.82
M16	71.50	88.90	22	27	51.30	54.10	2.35	2.87
Mean	69.99	86.84	23.38	26.50	52.30	53.29	2.68	3.01
C.V	7.31		8.41		7.48		11.54	
$LSD_{0.05}$	8.53		3.6		3.8		0.28	

of a wide genetic variability among the lines and *F*1-hybrids produced from them; indicating that the genetic improvement is possible in the present genetic material. Moreover, the wide range in the mean performance for the traits: plant height, number of pods per plant, 100-seed weight and yield; among the entries accompanied with high heritability (broad-sense) of 0.71 - 0.95 confirm the presence of sufficient genetic variability and possibility of selection and improvement of yield and yield traits in the present faba bean germplasm. Similar results were reported by [15] [16] [17].

4.2. General and Specific Combining Ability, Hetesosis and Production of Synthetic Cultivar

In any breeding program, it is very important to know the combining abilities of the inbred lines that are used as parents in hybrids [9] [18]. Combining ability helps the breeder to identify the best combiners which may be hybridized either to exploit heterosis or to build up favorable fixable genes [19] [20].

In the present investigation, the highly significant mean squares for both general combining ability (GCA) and specific combining ability may indicate the importance of both additive and dominance gene effect in the inheritance of the studied traits. Moreover, the higher mean squares from the analysis of variance for GCA of the traits than of SCA showed the great contribution of the additive effects of genes in the expressions of the traits. Therefore, selection will be effective for improvement of yield and yield traits in the present genetic material. Several researchers have reported on the significance of both general and specific combining ability effects on yield and yield traits in faba bean and found similar results, e.g. [20] [21].

Form the results, the highest GCA given by Hudeiba/93 line for plant height, number of pods per plant and number of seeds per pod and the highest GCA exhibited by Shabah line for 100-seed weight as well as that showed by Bassabier line for pods per plant and yield (t/ha), indicate that these lines are the good combiner for the mentioned traits; therefore the improvement of such traits is rather predictive and more heterosis and high yield performance could be expected upon crossing. These findings are in agreement with those reported by [16] [21] [22]. Moreover, the positive SCA exhibited by the crossing $L_2 \times L_4$ for plant height and pods per plant and that positive significant SCA effect given by the cross of Shabah × Selaim for 100-seed weight as well as the desirable positive SCA exhibited by all crosses for grain yield t/ha indicated that both additive and non-additive effects of the genes played a role in controlling faba bean yield as reported by [15] [17] [23] Therefore, as Hudeiba/93, Bassabier and Shabah lines exhibited the highest GCA and highest SCA upon crossing, they represent the presence of suitable genetic material for a breeder to build a future program to improve faba bean yield through selection and hybridization. The average amount of heterosis present in plant height (12.33%), number of pods per plant (64%), 100-seed weight (10.50%) and in yield t/ha (67%), indicate the presence of sufficient amount of heterosis, which could be used as a base for an effective breeding program for improvement of yield of the local faba bean gene in the semi-arid zone of Sudan. similar results were reported by other workers, e.g., [16] [17] [23] [24] [25].

In the present study the high degree of cross-fertilization of 36% and high heterosis (67%) exhibited by the lines under the study as well as their highly significant positive GCA and SCA indicate the presence of the prerequisites for production of synthetic cultivars. For the number of parental lines, the high and significant performance for yield and yield traits obtained by mixture M2 (the mixture of Hudeiba/93, Bassabier, Ed-Damar and Shabah lines) in Syn-0 and Syn-1 compared to performance of each of the line, indicate that synthetic cultivars could be developed from these four lines. Moreover, the increase in overall yield performance from 3.40 t/ha in Syn-0 to 3.96 in Syn-1 indicates the effect of heterozyosity as well as the joint effect of heterogeneity and hetrozygosity in Syn-1, which is expected to increase and give high yield performance in Syn-2 and Syn-3 [3] as maximum heterosis is not achieved in Syn-1 but could be realized in later generations [8]. [8] pointed out that the maximum amount of heterosis will take until Syn-4 to realize nearly maximum amount of heterosis as synthetic exploited more additive gene action compared with hybrid which exploited non additive genes [9] [26]. Moreover, and for maximum synthetic yield, it is recommended to increase the degree of cross-fertilization before commercialization as reported by [8] and [27].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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