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CLASSIFICATION OF MAIZE INBRED LINES INTO HETEROTIC GROUPS USING SPECIFIC COMBINING ABILITY EFFECTS FOR GRAIN YIELD

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ABSTRACT

In the maize hybrid development program, understanding general and specific combining ability of the inbred lines and their hybrids, forming and exploiting meaningful heterotic groups are key aspects for success. Twelve new yellow maize inbred lines, derived from four different genetic sources were used in this study. Two testers inbred lines; (Sk15 and Gz658) were crossed with the twelve inbred lines at Sakha Agricultural Research Station in 2022 summer season. A total of 24 F_1 crosses plus one check (Pioneer Single Cross 3444) were evaluated in a randomized complete block design with three replications at three Agricultural Research Stations in 2023 summer season for grain yield. The mean squares due to crosses and their partitions; lines, testers and lines × testers interaction were highly significant for grain yield. Also the results showed that non-additive gene effects were more important than additive gene effects in the inheritance of this trait. The two crosses (Sk5009/50 × Gz658) and (Sk5009/51 × Gz658) were significantly superior to the check for grain yield. The desirable inbred lines for general combining ability (GCA) effects were Sk5009/50, Sk5009/51, Sk5006/44 and Sk5006/45 for grain yield. The results showed that the best genetic source to isolate the desirable inbred lines for grain yield was the improved population Sk9 (C_2). The correlation coefficients between mean performance of crosses and their specific combining ability (SCA) effects based on Kempthorne and SCA effects based on Yang methods showed that the two methods were going in same direction, however the SCA effects of Yang method was higher for corresponding with mean performance than Kempthorne method, hence SCA effects of Yang method is more practical for maize breeder to selection. The best breeding efficiency for classifying the twelve inbred lines into heterotic groups was obtained by SCA effects based on Yang (74.0%), whereas SCA effects based on Kompthorne showed the lowest breeding efficiency (66.7%). Hence SCA effects of Yang proved particularly successful in classifying inbred lines of maize into heterotic groups.

Key words: ***GCA, SCA, Additive gene effects, Non-additive gene effects, Heterotic group, Crosses, Population, Breeding efficiency.***

INTRODUCTION

Maize is a versatile crop with a wide genetic variability and able to grow successfully throughout the world covering tropical, subtropical and temperate, agro-climatic conditions. Every part of the maize plant has an economic value; the grain, leaves, stalk, tassel and cob can all be used to produce a large variety of food and non-food products. Globally, maize as a cereal crop ranked third in importance fallowed by wheat and rice, but maize is expected to overtake rice as the world's most important grain by 2030, owing to rising demand for dairy and meet products in developing countries and declining rice production in China and India (Salvi *et al* 2007). Selection of parental lines in hybrid breeding programs is a vital task for breeder. Therefore, it is necessary to choose the parental lines accordingly with the help of combining ability analysis and there is a continuous need to evolve new hybrids, which should exceed the existing hybrids in yield (Mir *et al* 2015). Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis. It is also important to have information on the nature of combining ability of parents, their behavior and performance in hybrid combinations (Chawla and Gupta 1984). Combining ability is categorized into general combining ability and specific combining ability. GCA is the average of line performance in their hybrids, while SCA refers to when some hybrid combinations are better or worse than the average performance of the parents (Hallauer *et al* 1988). Additionally information on combining abilities can be used to classify inbred lines into distinct heterotic groups. Heterotic groups comprise related or unrelated genotypes that exhibit similar combining ability (Warburton *et al* 2002). This classification is pivotal for effective hybrid breeding programs, as it enables breeders to strategically select parental lines from specific heterotic groups to maximize heterosis and develop hybrids with superior performance (Akinwale 2021). The identification of inbred lines that form superior hybrid is the most costly and time consuming phase in maize hybrid development. Heterotic grouping facilitates the development of superior hybrids, enhancing the efficiency of hybrid breeding programs and maximizing hybrid vigor (Carena and Hallauer 2001). By categorizing inbred lines into specific heterotic groups, breeders can systematically create and testing, thereby saving time and resource (Labroo *et al* 2021). Also, grouping helps in developing hybrids that are better adapted to specific environmental conditions. In general heterotic grouping was done by considering the specific combining ability effects of grain yield as proposed by Vasal *et al* (1992 a, b); an inbred line that possess negative SCA effects value with any one of a heterotic tester was grouped with that tester. The value of SCA effects reveals the genetic relationship of two parents; high SCA value means far genetic relationship which would be close if they have low SCA value (Fan *et al* 2009).Generally the findings of the heterotic grouping of maize inbred lines significantly contribute to sustainable agriculture by enabling the development of high yielding, resilient hybrids, which offer substantial environmental and economic benefits. The breeding efficiency results highlight the importance of selecting appropriate methods to make heterotic groups and parental combinations to achieve specific breeding goals. This aligns with previous studies by Fan *et al* (2009), Akinwale *et al* (2014), Amegbor *et al* (2017) and Mosa *et al* 2024 c).The objectives of the present study were to estimate combining abilities of twelve new yellow maize inbred lines, using SCA effects based on both Kempthorne and Yang methods for classifying tested inbred lines into heterotic groups and comparing breeding efficiency between them.

MATERIALS AND METHODS

This study included twelve new yellow maize inbred lines which were derived from four different genetic sources at Sakha (Sk) Agricultural Research Station. Detailed description of the inbred lines is shown in Table (1). The two yellow inbred lines Sk15 and Gz658 as testers were crossed with the 12 yellow inbred lines by line × tester mating design at Sakha Agricultural Research Station in 2022 summer season. The resultant 24 F_1 hybrids plus one check (Pioneer SC3444) were cultivated in a randomized complete block design with three replications at the three Agricultural Research Stations; Sakha, Nubaria and Mallawi in 2023 summer season. The plot included one row, 6m length with 0.8m spacing between rows. All other management practices such as fertilizer application, intercultural operations and harvesting were performed as the recommended package of practices. The grain yield was calculated in ardab per feddan [ardab (ard) = 140kg and feddan (fed) = 4200m^2] which was adjusted at 15.5% grain moisture. As a result of the emergence of homogeneity between trials at three locations according to test of Bartlett (1937), the combined analysis was done across three locations according to Snedecor and Cochran (1989), using computer application of Statistical Analysis System (SAS 2008). Line × tester analysis was performed according to Kempthorne (1957) as explained by Singh and Chaudhary (1985).

Table 1. Name and Source for12 new yellow maize inbred lines.

Name	Source
Sk5002/39	Un-improved population Sk22
Sk5002/40	
Sk5002/41	
Sk5006/44	Single Cross 1(SC-Sk-1)
Sk5006/45	
Sk5006/46	
Sk5008/47	Single Cross 2(SC-Sk-2)
Sk5008/48	
Sk5008/49	
Sk5009/50	Improved population Sk9 (C_2)
Sk5009/51	
Sk5009/52	

AGD-R Software (Analysis of Genetic Designs in R for windows) version 5.0 Statistical software was used to calculate variances and effects (Rodriguez *et al* 2015). Equation for SCA effects estimation according to Kempthorne (1957) was as follows: $(S_{ij}) = X_{ij}-\bar{x}_{i.}-\bar{x}_{.j}+\bar{\bar{x}}$, where S_{ij} is the SCA effects of cross, X_{ij} is the mean yield of the cross between the ith line and jth tester, $\bar{x}_{i.}$ is the mean yield of the ith line in their crosses and $\bar{x}_{.j}$ is the mean yield of the jth tester in their crosses and $\bar{\bar{x}}$ is the mean of all crosses. While, estimation for SCA effects from Tian *et al* (2015) was performed according to Yang (1983) as follows: $(S_{ij}) = X_{ij}-(\bar{x}_{i.}+\bar{x}_{.j})/2$. SCA effects of Kempthorne and SCA effects of Yang were used to classify 12 inbred lines in this study into heterotic groups according to Vasal *et al* (1992 a, b). The breeding efficiency of SCA effects method to classifying inbred lines was calculated according to Fan *et al* (2009), Badu-Apraku *et al* (2016) and Bhatla *et al* (2024), the following equation was used:

$$\textbf{Breeding efficiency} = \frac{\frac{\textbf{HY INTERGH}}{\textbf{TN INTERGH}} \times \textbf{100} + \frac{\textbf{LY INTRAGH}}{\textbf{TN INTRAGH}} \times \textbf{100}}{\textbf{2}}$$

Where, HY INTERGH = numbers of high-yielding inter-heterotic group hybrids; TN INTERGH = total number of inter-heterotic group hybrids; LY INTRAGH = number of low-yielding intra-heterotic group hybrids; TN INTRAGH = total number of intra-heterotic group hybrids. The relative importance of additive gene effects (GCA) and non-additive gene effects (SCA) was calculated according to Baker (1978), modified by Hung and Holland (2012).

RESULTS AND DISCUSSION

Mean squares of line × tester analysis of 24 crosses for grain yield across three locations are presented in Table (2). The locations (Loc) mean squares were significant, reflecting that the soil and climate conditions varied among the three locations. The results showed that crosses (C) and their partitions; lines (L), testers (T), and interaction of (L×T) exhibited highly significant differences among themselves for grain yield, indicating adequate variability materials for making valid experimentation and inferences.

Table 2. Mean squares of line × tester analysis of 24 crosses for grain yield across three locations.

SOV	df	SS	MS
Locotions (Loc)	**2**	**586.54**	**293.27***
Rep/Loc	**6**	**251.49**	**41.92**
Crosses (C)	**23**	**1640.37**	**71.32****
Lines (L)	**11**	**949.09**	**86.28****
Testers (T)	**1**	**45.84**	**45.84****
L×T	**11**	**645.45**	**58.68****
C×Loc	**46**	**1372.82**	**29.84****
L×Loc	**22**	**573.05**	**26.05****
T×Loc	**2**	**442.21**	**221.10****
LxT×Loc	**22**	**357.56**	**16.25****
Error	**138**	**906.03**	**6.57**
$2K^2$ GCA/$2K^2$ GCA+K^2 SCA		**0.25**	

Significance levels are indicated as follows: **=P≤0.01; *=P≤0.05.

The mean squares due to crosses × locations (C × Loc) and their partitions; (L × Loc), (T × Loc) and (L × T × Loc) were highly significant, indicating that the crosses and their partitions were greatly affected by changing locations. The ratio between twice the K^2GCA component to total genetic effects (2K^2GCA + K^2SCA) was 0.25, meaning that non-additive gene effects was more important than additive gene effects in the inheritance of grain yield. Similar results of importance of non-additive gene effects in the inheritance of grain yield were reported by Ejigu *et al* (2017), Mbuvi *et al* (2018), El-Gazzar (2021) and Mosa *et al* (2024a).

Mean performances of 24 crosses and their superiority% relative to the commercial hybrid SC3444 for grain yield across three locations are presented in Table (3).

Table 3. Mean performance of 24 crosses and their superiority relative to commercial hybrid SC 3444 for grain yield across three locations.

Inbred line	Grain yield (ard/fed)		Superiority% relative to the check SC3444	
	Tester		Tester	
	Sk15	Gz658	Sk15	Gz658
Sk5002/39	23.83	21.36	-17.14**	-25.75**
Sk5002/40	24.94	19.64	-13.29**	-31.74**
Sk5002/41	28.10	25.79	-2.31	-10.33*
Sk5006/44	28.99	28.33	0.77	-1.52
Sk5006/45	25.92	30.29	-9.90*	5.29
Sk5006/46	24.50	27.64	-14.83**	-3.91
Sk5008/47	25.67	25.65	-10.75*	-10.82*
Sk5008/48	26.18	28.96	-8.99*	0.67
Sk5008/49	27.39	26.16	-4.77	-9.05*
Sk5009/50	25.65	31.37	-10.83*	9.06*
Sk5009/51	25.54	32.05	-11.21*	11.42**
Sk5009/52	27.29	27.82	-5.12	-3.28

***, ** indicate significant at the 0.05 and 0.01 levels of probability, respectively**
LSD; 0.05 = 2.39 and 0.01 = 3.15.

The range of mean performance for crosses grain yield (ard/fed) varied from 19.64 ard/fed for (Sk5002/40×Gz658) to 32.05 ard/fed for (Sk5009/51×Gz658), with a grand mean of 25.84 ard/fed. Fourteen crosses showed grain yield over grand mean and 10 crosses were lower than grand mean. The two crosses (Sk5009/50×Gz658) of 31.37 ard/fed and

(Sk5009/51×Gz658) of 32.05 ard/fed had significant superiority relative to the check (SC3444) 28.77 ard/fed for grain yield with 9.06% and 11.42%, respectively. Meanwhile the three crosses; (Sk5006/44×Sk15), (Sk5006/45×Gz658) and Sk5008/48×Gz658) had higher yield than the check but not significant for grain yield. Superior cross combinations are required to the new hybrid production program.

GCA effects of 12 inbred lines and two testers and SCA effects of 24 crosses using Kempthorne and Yang methods for grain yield are presented in Table (4). The best tester for GCA effects was Gz658. The highest and desirable inbred line for GCA effects (positive and significant) was Sk5009/51 followed by Sk5006/44, Sk5009/50 and Sk5006/45. The lowest inbred line for GCA effects (negative and significant) was Sk5002/40 followed by Sk5002/39. The highest genetic source for GCA effects was improved population Sk9 (C2) 1.659 which give two inbred lines had desirable for GCA effects. The lowest genetic source for GCA effects was the population Sk22 (not improved) -2.684 which gave two inbred lines that had the lowest values for GCA effects. These results suggest that the best genetic source for isolating the desirable inbred lines in GCA effects for grain yield is the improved population. Hallauer *et al* (1988) stated that the development of elite maize inbred lines depends on the improvement of germplasm sources that may include both genetically narrow and broad populations.

According to SCA effects of Kempthorne, the best genetic source which gave crosses that had the highest SCA effects was the population Sk22 with tester Sk15 (2.142); same population gave the lowest crosses for SCA effects with tester Gz658 (-2.142). Meanwhile according to SCA effects ofYang, results showed that the best genetic source for giving the highest crosses for SCA effects was the improved population Sk9 (C2) with tester Gz658 (2.725),meanwhile the reverse was obtained by population Sk22 with tester Gz658 (-3.253). These results indicate that the un-improved population Sk22 as a source for isolation gaves the highest and the lowest crosses for SCA effects according to Kempthorne. Meanwhile according to Yang method, the improved population Sk9 (C2) gave the highest crosses for SCA effects and un-improved population Sk22 gave the lowest crosses for SCA effects.

Table 4. General combining ability effects (GCA) of 12 inbred lines and two testers and specific combining ability effects (SCA) of 24 crosses using Kempthorne and Yang methods for grain yield across three locations.

Inbred line	Source	GCA effects	SCA effects-Kempthorne		SCA effects-Yang	
			Tester		Tester	
			Sk15	Gz658	Sk15	Gz658
Sk5002/39	Un-improved population Sk22	-4.031**	1.698	-1.698	-0.548	-3.483**
Sk5002/40		-4.339**	3.113**	-3.113**	0.713	-5.053**
Sk5002/41		0.319	1.614	-1.614	1.543	-1.224
Mean		-2.684	2.142	-2.142	0.570	-3.253
Sk5006/44	Single cross 1	2.030**	0.789	-0.789	1.574	0.456
Sk5006/45		1.474*	-1.725*	1.725*	-1.218	2.693**
Sk5006/46		-0.558	-1.110	1.110	-1.619	1.061
Mean		0.982	-0.682	0.682	-0.421	1.403
Sk5008/47	Single cross 2	-0.964	0.471	-0.471	-0.241	-0.723
Sk5008/48		0.942	-0.929	0.929	-0.688	1.630
Sk5008/49		0.150	1.076	-1.076	0.920	-0.770
Mean		0.042	0.206	-0.206	-0.003	0.046
Sk5009/50	Improved population Sk9 (C2)	1.882**	-2.400**	2.400**	-1.690	3.571**
Sk5009/51		2.168**	-2.794**	2.794**	-1.941*	4.108**
Sk5009/52		0.929	0.196	-0.196	0.430	0.498
Mean		1.659	-1.666	1.666	-1.067	2.725
GCA effects for tester			-0.461*	0.461*		

***, ** indicate significant at the 0.05 and 0.01 levels of probability, respectively.**
LSD g_i for lines at 0.05 = 1.194 and at 0.01 = 1.577
LSD g_i-g_j for lines at 0.05 = 1.719 and at 0.01 = 2.295
LSD g_i for testers at 0.05 = 0.496 and at 0.01 = 0.663
LSD g_i-g_j for testers at 0.05 = 0.702 and at 0.01 = 0.937
LSD S_{ij} for crosses at 0.05 = 1.719 and at 0.01 = 2.295
LSD S_{ij}-S_{kl} for crosses at 0.05 = 2.431 and at 0.01 = 3.246

Hence this study indicated that SCA effects of Yang are more acceptable than those of Kempthorne. Hallauer *et al* (1988) stated that the improvement of populations may by either for use as genetic source for isolating new inbred lines or for use by farmer as populations *per se* or in hybrid combinations. Also, the result showed that the four crosses (Sk5002/40×Sk15), (Sk5006/45×Gz658), (Sk5009/50×Gz658) and (Sk5009/51×Gz658) had positive and significant SCA effects according to Kempthorne, last three from them had highly significant SCA effects according to Yang. Hence the two methods were differing in one cross (Sk5002/40×Sk15), this cross had highly significant SCA effects of Kempthorne and not significant according to Yang; whereas, this cross had lower mean performance (24.94 ard/fed) than the grand mean (25.84 ard/fed), therefore Yang method is more accurate than Kempthorne method in estimation of SCA effects for this cross.

We noticed in the many researches that used Kempthorne method no high correspondence between SCA effects and mean performance for crosses. Hence we calculated simple correlation coefficients between mean performance of crosses and their SCA effects according to Kempthorne and SCA effects according to Yang for grain yield (Table 5).

Table 5. Simple correlation coefficients between mean performance of crosses and their SCA effects according to Kempthorne and SCA effects according to Yang of crosses for grain yield.

Correlationcoefficient	Means performance	SCA effects of Kempthorne
SCA effects of Kempthorne	0.627**	-
SCA effects of Yang	0.944**	0.850**

**** Indicate significant at 0.01 level of probability.**

The results showed that the highest correlation coefficient was obtained between SCA effects of Yang and mean performance of crosses (0.964**). While, the lowest correlation coefficient was between SCA effects of Kempthorne and mean performance of crosses (0.627**). Meanwhile the correlation coefficient between SCA effects of Kempthorne and SCA effects of Yang methods was positive and highly significant (0.850**). From above results the two methods were going in the same direction; however, the Yang method showed high correspondence between SCA effects and mean performances of crosses, hence it is more practical for maize breeders to selection of superior hybrids compared with Kempthorne method. Same results were obtained by Rong (1983), Wu *et al* (2006) and Mosa *et al* (2024 c).

Estimates of heterotic croups using SCA effects of both Kempthorne and Yang for grain yield across three locations are presented in Table (6). The results based on the SCA effects method for classification the 12 inbred lines into two heterotic groups: group (A) of tester Sk15, and group (B) of tester Gz658, depending on SCA effects for crosses according to Kempthorne, the results showed that group (A) included the inbred lines: Sk5006/45, Sk5006/46, SkS008/48, Sk5009/50 and Sk5009/51, while the group (B) included the inbred lines: Sk5002/39 Sk5002/40, Sk5002/41, SkS006/44, Sk5008/47 Sk5008/49 and Sk5009/52.

Table 6. Estimates heterotic groups using SCA effects of both Kempthorne and Yang for grain yield.

Inbred line	SCA effects of Kempthorne		SCA effects of Yang	
	Sk15 (A)	Gz658 (B)	Sk15 (A)	Gz658 (B)
Sk5002/39	-	B	-	B
Sk5002/40	-	B	-	B
Sk5002/41	-	B	-	B
Sk5006/44	-	B	-	-
Sk5006/45	A	-	A	-
Sk5006/46	A	-	A	-
Sk5008/47	-	B	-	B
Sk5008/48	A	-	A	-
Sk5008/49	-	B	-	B
Sk5009/50	A	-	A	-
Sk5009/51	A	-	A	-
Sk5009/52	-	B	-	-

Meanwhile the groups according to Yang method, found, that all the inbred lines in groups A and B were similar with groups according Kempthorne, except the two inbred lines Sk5006/44 and Sk5009/52; this method was not able to classify. The SCA effects help breeders to determine heterotic patterns among inbred lines to identify promising single crosses and assign them into heterotic groups (Vasal *et al* 1992 a, b and Minker *et al* 2004).

Comparing the breeding efficiency of SCA effects of Kempthorne and SCA effects of Yang methods for classifying 12 maize inbred lines into heterotic groups are presented in Table (7). Twenty-four crosses were arranged in descending order based on their mean gain yield across three locations. The highest breeding efficiency was obtained according to SCA effects of Yang (74.3%) whereas, according SCA effects of Kempthorne showed the lowest efficiency (66.7%). Hence SCA effects of Yang proved particularly successful in classifying inbred lines into heterotic groups. The breeding efficiency results highlight the importance of selecting appropriate methods and parental combinations to achieve specific breeding goals. These results are in line with previous studies by Fan *et al* (2009), Akinwale *et al* (2014), Amegbor *et al* (2017) Mosa *et al* (2024 b, c) and Bhatla *et al* (2024).

Table 7. Breeding efficiency of SCA effects method of both Kempthorne and Yang to make heterotic groups for grain yield.

Yield group	Cross type	SCA effects of Kempthorne	SCA effects of Yang
25.85-32.05	Inter-group	9	11
	Intra-group	5	3
19.64-25.84	Inter-group	3	3
	Intra-group	7	7
No. of inter-group		12	14
No. of intra-group		12	10
Breeding efficiency		66.7%	74.3%

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تقسيم سلالات من الذرة الشامية إلى مجاميع هجينية بإستخدام تأثيرات القدرة الخاصة على الإئتلاف لمحصول الحبوب

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*معرفة القدرة العامة والخاصة على الإئتلاف للسلالات وللهجن الناتجة منها وعمل المجاميع الهجينية وإستغلالها هى أساس النجاح فى برامج إنتاج هجن الذرة الشامية. تم التهجين بين ١٢ سلالة جديدة من الذرة الشامية الصفراء والناتجة من ٤ مصادر وراثية مختلفة مع إثنين من السلالات الكشافة وهى: (**Sk15**) و (**Gz658**) بمحطة بحوث سخا موسم ٢٠٢٢. تم تقييم الهجن الناتجة وعددها ٢٤ هجين بالإضافة إلى هجين المقارنة هجين فردى بايونير ٣٤٤٤ فى تجربة بإستخدام تصميم القطاعات الكاملة العشوائية فى ثلاث مكررات موسم ٢٠٢٣ فى ثلاث محطات بحثية لدراسة صفة محصول الحبوب. أظهرت النتائج أن التباينات الراجعة إلى الهجن ومجزأتها: السلالات والكشافات والسلالة × الكشاف كانت عالية المعنوية لصفة محصول الحبوب. كانت تأثيرات الفعل الوراثى غير المضيف هى المتحكمة فى وراثة هذه الصفة. أظهر الهجينين (**Sk5009/50×Gz658**) و (**Sk5009/51×Gz658**) تفوقاً معنوياً على هجين المقارنة فى صفة محصول الحبوب. السلالات المرغوبة فى تأثيرات القدرة العامة على الإئتلاف لمحصول الحبوب هى (**Sk5009/50**) و (**Sk5009/51**) و (**Sk5006/44**) و (**Sk5006/45**). أظهرت النتائج أن أفضل المصادر الوراثية فى العزل للحصول على سلالات مرغوبة فى تأثيرات القدرة العامة على الإئتلاف هى العشيرة المحسنة (**Sk9 (C_2)**). أظهرت النتائج أن معامل التلازم بين متوسط الأداء للهجن وتأثيرات القدرة الخاصة على الإئتلاف المقدرة عن طريق **Kempthorne** أوعن طريق **Yang** أن التلازم بين الطريقتين معنوياً وفى إتجاه واحد ، ومع ذلك كان التلازم بين متوسطات الهجن وتأثيرات القدرة الخاصة على الإئتلاف المقدرة بطريقة **Yang** أكثر تطابقاً مقارنةً بطريقة **Kempthorne** ، وبالتالى فإن تقدير تأثيرات القدرة الخاصة على الإئتلاف بطريقة **Yang** تكون عملية أكثر للمربى فى الإنتخاب. كانت أفضل طريقة فى عمل المجاميع الهجينية هى لتأثيرات القدرة الخاصة على الإئتلاف المقدرة بطريقة **Yang** حيث كانت فاعليتها٧٤% مقارنةً بتأثيرات القدرة الخاصة على الإئتلاف المقدرة بطريقة **Kempthorne** حيث كانت فاعليتها ٦٦,٧% ، وبالتالى تقدير تأثيرات القدرة الخاصة على الإئتلاف بطريقة **Yang** أثبتت نجاح أعلى بخصوص عملية تصنيف السلالات إلى مجاميع هجينية.*

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