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Research Article

Performance of Provitamin a Maize Hybrids for Yield and Desirable Agronomic Traits

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Abstract

To find improved F1 hybrids for breeding procedures, the heterosis of maize hybrids must be determined. Therefore, to identify prospective hybrids for use in future provitamin A maize breeding systems, this study was carried out to evaluate the amount of standard heterosis for grain yield and related attributes. Fifteen provitamin A maize inbred lines were crossed through the diallel-II design. The resulting Eight four F1 hybrids along with four standard checks (BHQPY545, BH549, BH546, and BH547) were evaluated using RCBD (20 entries) and Alpha-Lattice Design (68 entries) with two replications during 2022/2023 main cropping season at Bako National Maize Research Center. Analysis of variance revealed significant variations for most of the traits indicating the existence of genetic variability. The Standard heterosis assessment noticed significant positive and negative heterosis for the majority of the traits investigated. Cross combinations over BHQPY 545, such as L10 × L3, L10 × L6, and L13×L12, demonstrated the largest proportion of traditional heterosis for grain yield (more than 25% yield advantage). Because BH546 and BH547 are normal maize with grain production potential, the majority of crossings yielded negative and significant results over commercial checks. The highest found heterosis for grain yield and associated factors indicated that maize genotypes' heterotic potential may be beneficial to boost yield. The findings of this study could be valuable for researchers looking to develop high-yielding provitamin A maize hybrids. As a result, possible hybrids might be recommended for commercial usage once the results have been verified by repeating the research over time and across places, as well as incorporating quality attributes analysis data.

Keywords

Biofortification, F1 Hybrids, Single Cross, Standard Heterosis, Desirable Gene

1. Introduction

Maize, or corn (Zea mays L.), was first domesticated in southern Mexico and Mesoamerica almost 9,000 years ago [3, 20]. Maize is a highly adaptable and versatile crop as compared to wheat and rice and is utilized in various industrial and energy applications. In developed countries, maize is predominantly utilized as a feed crop for cattle [8, 9]. However, Africa contributes only 8% to the global maize production, producing 97 million tons [11]. Despite this, maize is a significant cereal crop globally, producing 1210 million tons in 2021 and serving as a vital food source for both human and livestock consumption [12, 35].

Maize, known as corn, is immensely important in global agricultural systems. Several researchers have thoroughly investigated and proven its diverse and dynamic function [15, 27, 29,

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32]. Maize and its products account for 65% of Africa's food supply, 30% in America, and 6.5% in Asia, demonstrating its critical importance in food security and economic development [28]. Plus, maize is a well-established and important human food crop in many countries, including Sub-Saharan Africa, Latin America, and a few Asian countries, accounting for more than 20% of total food calories [32]. Maize is an important staple grain for nearly 200 million people worldwide, providing 15% of protein and 20% of calories. Economic development, such as increased incomes and urbanization, is driving up maize demand. This has resulted in a considerable increase in animal-based food consumption. Asia demonstrated this trend [8]. Maize is a dynamic and flexible crop that is critical to global agri-food systems, making a significant contribution to food and nutrition security [15, 27, 29, 32].

The existence of micronutrients in plant-based feed and food has been proven to considerably improve the health and well-being of both animals and people. To ensure ideal crop output and nutritional value, maize plants must be farmed with appropriate micronutrient levels [35]. Maize, often known as maize, comes in a variety of varieties, including sweet corn, waxy corn, popcorn, and baby corn, all of which are widely consumed by people of all ages across the country. These varieties contain high levels of protein and vitamin A, making them a wonderful supplement to any diet. Yellow maize is particularly healthy because it contains both pro-vitamin A and non-pro-vitamin A carotenoids, which can considerably improve human health. As a result, it is strongly advised that we incorporate maize into our diet to get its health benefits. [1, 19]. Maize is a substantial source of calories in the daily diet, but it does not provide full nutrition since it lacks critical amino acids, minerals, and vitamins [16, 18, 17, 28].

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Biofortification involves breeding nutrient-dense crops to increase their nutritional value and alleviate micronutrient shortages. It is an affordable and sustainable solution to malnutrition. [4, 25, 36] suggest biofortification to boost micronutrient levels in staple crops and prevent malnutrition. Genetic manipulation and conventional breeding can modify grain composition and quality in biofortified maize grains [26]. As a result, a thorough understanding of genetic performance and desirable characteristics in breeding populations is crucial to the success of any genetic improvement effort, particularly for biofortified maize. Maize is Ethiopia's most popular cereal crop due to its versatility, flavor, and high grain production. Creating maize with multi-nutritional qualities is the primary goal of Ethiopia's breeding program. The program focuses on provitamin A biofortification through recurrent and pedigree selection and conversion of white lines into yellow lines. Each year, Ethiopia's national maize program develops new provitamin A maize inbred lines for breeding and hybridization, yielding imaginative provitamin A maize single crossings. These crossings are made from inbred lines adapted to mid-altitude agroecology in Ethiopia using the diallel method-II, and hybrid performance and desired traits are determined. This study analyzes the hybrid performance of provitamin A maize crosses in terms of grain production and evaluates the desirable characteristics of inbred lines suitable for Ethiopia's mid-altitude agroecology.

2. Materials and Methods

2.1. Description of Experimental Sites

The studies were carried out at Bako National Maize Research Center (BNMRC) during the 2022 cropping season. The BNMRC is located in the East Wollega zone of the Oromia Regional State in Western Ethiopia. BNMRC is located in sub-humid agroecology, between 9 °06' north latitude and 37 °09' east longitude, at an elevation of 1650 meters above sea level. The mean minimum and maximum temperatures at this location are 19.7 ℃ and 22.7 ℃, respectively. The site's long-term annual rainfall is 1245 mm, with a relative humidity of 63.55%. The soil type at BNMRC is reddish brown in color, with a clay and loam texture and a pH of 6.0 to 5.9 [13].

2.2. Experimental Materials

The two analyzed trials included 18 F1 hybrids with two checks (BHQPY545 and BH549) and 66 F1 hybrids with two checks (BH546 and BH547), respectively. In the 2021/2022 cropping season, 84 F1 hybrids were generated at Bako National Maize Research Center utilizing the diallel method-II from 15 parental lines (Table 1), which were developed as early-generation germplasm for provitamin A inbred lines.

Table 1. List of inbred lines used in cross formation for experiment.

Lines	Code	Pedigree	Source Of Genotype
1	L1	MM1300043-B-1-1-1-B-1-1	EIAR-BNMRC
2	L2	MM1400001-77-1-2-1-1-B	EIAR-BNMRC
3	L3	MM1300052-B-7-1-1-B-1-1	EIAR-BNMRC
4	L4	MM1300043-B-13-1-2-B-1-1	EIAR-BNMRC
5	L5	MM1300079-B-11-1-4-B-1-1	EIAR-BNMRC
6	L6	MM1400001-93-3-1-1-2-B	EIAR-BNMRC
7	L7	MM1300094-6-1-2-B-1-1	EIAR-BNMRC
8	L8	MM1201002-B	EIAR-BNMRC
9	L9	MM1801001-B	EIAR-BNMRC
10	L10	MM0001010	EIAR-BNMRC
11	L11	MM1400001-89-2-1-2-2-B	EIAR-BNMRC
12	L12	MM1100001-173-2-1-2-1-1-1	EIAR-BNMRC
13	L13	MM1300052-B-7-3-2-B-1-1	EIAR-BNMRC
14	L14	MM1300043-B-1-1-1-B-1-1	EIAR-BNMRC
15	L15	MM1300071-B-13-1-3-B-1-1	EIAR-BNMRC

**EIAR-BNMRC=Ethiopian Institute of Agricultural Research of Bako National Maize Research Center

2.3. Experimental Design and Field Management

Two experiments, hybrid and inbred, were conducted during the main cropping season of 2022/2023. The hybrid trial consisted of 18F1 and 66F1 experimental crosses, along with two standard checks. It was planted using the RCBD and 17x4 alpha lattice experimental designs, respectively, with two replications. Each entry was planted in a 5-meter-long row plot. Two seeds were planted per hill, then trimmed to one per station to achieve a final plant density of 53,333 plants per hectare. NPS and urea fertilizers were applied at rates of 150 and 250 kg/ha, respectively. The recommended agronomic practices were followed for each location.

2.4. Data Collection

Data on grain yield and other important agronomic parameters were collected on a plot and sampled from plant bases. Days to 50% silking (DS), field weight (FW) (kg/plot), plant aspects (PA), ear aspects (EA), and bad husk cover (HC) were collected on a plot basis. In contrast, ear height (EH) (cm) and plant height (PH) (cm), root lodging (RL), stock lodging (SL), and major diseases such as gray leaf spot (GLS), turcicum leaf blight (TLB), as well as common leaf rust (CLR) were recorded on a sampled plant basis.

2.5. Data Analysis

SAS 9.4 [31] was utilized to conduct statistical variance analysis on the data for each character. Before analysis, the HC and ER data were adjusted through square root transformation [14]. The least significant difference will be used to distinguish significant means at the 5% probability level (LSD=0.05). For characteristics with statistically significant variations between genotypes, standard heterosis (SH) in percentage was estimated as per [10] method. The SH values were calculated as a percentage increase or decrease in cross-performance above the best standard check. Specifically, SH (%) = (F1-SV)/SV*100, where F1 represents the mean value of a cross and SV represents the mean value of the standard check variety. The heterosis significance was determined using the t-test. To determine the standard errors of the difference for heterosis, the following procedure should be followed: SE(d) for SH should be computed as $(\pm\sqrt{2MSE})/r$. SE(d) represents the standard error of the difference, while MSE is the error mean square, and r indicates the number of replications. After calculating the estimated t-value, it should be compared to the tabulated t-value at the degree of freedom of error. Finally, calculate the t (standard check) as F1 minus SV divided by SE(d) to obtain the desired results.

3. Results and Discussion

3.1. Analysis of Variance for Yield and Related Traits Estimated by Using RCBD and Alpha Lattice Design

The analysis revealed significant differences (P ≤ 0.05) among genotypes in grain yield, days to anthesis, days to silking, ear height, ear position, common leaf rust, stock lodging percentage, and plant aspect. Plant height was significantly significant (P < 0.01). All investigated characteristics differed significantly between hybrids, demonstrating sufficient genetic variation among genotypes. However, there was no significant difference in anthesis silking interval, grey leaf spot, root lodging percentage, ear rot percentage, or husk cover percentage (Table 2). The findings of the analysis of variance show that there were no significant differences between the investigated genotypes for any of the investigated parameters, showing a lack of variability. However, it is crucial to note that there are indeed notable genotypic distinctions in maize that can be utilized for future breeding endeavors.

The data was analyzed using ANOVA to determine genotypic effects. Mean comparisons were made using the LSD test at 1% and 5% levels of significance. Variance analysis was done using an alpha lattice design (17x4) with entry and block arrangements, and SAS 9.4 software packages were used for estimating variance features. Table 3 analysis showed significant differences (P<0.01) in genetic traits such as grain yield, days to anthesis, days to silking, plant height, ear height, and ear aspect. Gray leaf spot also exhibited a highly significant difference, indicating diverse responses to foliar diseases. Ear position and plant aspect (P<0.05) showed diversity among genotypes in performance features. Maize breeding programs rely on naturally variable genes to select high-yield maize kernels that have essential genes for vitamin A and protein. The genetic diversity across tested genotypes enables breeders to select optimal hybrids, and significant differences between materials indicate genetic variation, which allows for future breeding and obtaining favorable alleles. The findings strongly support the studies conducted by [21, 23]. The distinction between the two designs used for the same genotypes was primarily due to non-additive gene interactions. This was due to a combination of microenvironmental effects and interactions with both additive and non-additive elements, leaving no room for doubt. The trial was rigorously conducted in several locations and using diverse designs, which undoubtedly contributed to the observed diversity in quantitative features.

Table 2. Mean squares from analysis of variance for yield and yield-related traits evaluated by using RCBD design at Bako National Maize Research Center, West Shewa Ethiopia in 2022.

Source of Variation	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	CLR	SLP	RLP	PA	EA	ERP	HCP
Entry	1.53*	5.57*	6.9*	1.063	361.3**	278.2*	0.0026*	2.2	2.75	4.18*	32.2*	28.9	1.27*	1.8	6.87	11.98
Rep	0.01	1.6	8.1	2.5	102.4	75.6	0.00056	3.6	8.1	3.023	3.72	18.9	1.6	6.4*	8.87	0.64
Block (Rep)	0.65	4.48*	15.97*	0.92	950.7**	104.3	0.00061	2.4	2.25	1.6	23.36	2.97	0.57	1.01	6.87	9.72
Error	0.59	1.34	1.95	1.001	63.1	65.5	0.0008	2.3	2.7	1.24	13.09	0.17	0.38	1.04	0.086	0.064
CV (%)	11.67	1.4	1.66	7.09	4.06	9.4	6.42	34.2	34.1	28.05	32.2	33.9	15.69	23.5	32.3	29.25

Note: DA=days to anthesis, DS=days to silking, ASI=anthesis silking interval, PH=plant eight, EH=ear height, EPO=ear position, GY=grain yield, GLS= gray leaf spot, TLB=Turcicum leaf blight, CLR=common leaf rust, SLP=stock lodging percentage, RLP= root lodging percentage, PA= plant aspect, EA= ear aspect, ERP= ear rot percentage and HCP= husk cover percentage *and** significant at P<0.05 and P<0.01 respectively.

Table 3. Mean squares from analysis of variance for yield and yield-related traits evaluated by using Alpha Lattice (17x4) design at Bako National Maize Research Center, West Shewa, Ethiopia in 2022.

Source of Variation	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	PA	EA
Entry	3.73**	13.5**	15.2**	0.34	473.8**	264.86**	0.004*	2.67**	1.88	0.94*	2.1**
Rep	2.63	9.15*	47.1*	0.74	743.6*	795.89*	0.003	52.5**	57.6**	2.3*	7.52*

Source of Variation	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	PA	EA
Block (Rep)	2.71*	36.03*	10.11*	0.48	268.04	57.24	0.001	3.85*	2.8	1.3*	0.67
Error	1.11	2.64	2.96	0.31	135.6	76.68	0.0024	0.89	1.45	0.54	0.75
CV (%)	16.96	2.16	2.25	3.49	5.34	8.5	10.19	23.02	21.4	17.09	18.01

Note: *=0.05 and **= 0.01 significant probability levels respectively. DA=days to anthesis, DS=days to silking, ASI=anthesis silking interval, PH=plant eight, EH=ear height, EPO=ear position, GY=grain yield, GLS= gray leaf spot, TLB=Turcicum leaf blight, PA= plant aspect, and EA= ear aspect

3.2. Mean Performance of Provitamin a Maize Genotypes

The mean grain yield (GY) ranged from 4.79 ton ha-1 for BH545 to 8.07 ton ha-1 for L10XL6, with an overall average of 6.57 ton ha-1 for genotypes assessed using the RCBD design. About 15 crosses had a higher mean GY than BH546, although the quality protein maize (BHQPY545) commercial check had a lower GY than any of the other novel single crosses of provitamin A maize (Table 4). In other words, the average grain yield (GY) varied from 1.75 ton ha-1 for L5xL6 to 9.11 ton ha-1 for L8xL12, with an overall mean of 6.21 ton ha-1 for genotypes evaluated with the Alpha lattice design. About 11 single crosses of provitamin A maize provided a greater quantity of grain than the normal maize three-way cross of commercial check BH546, but only one single cross of provitamin A maize yielded more than the normal three-way commercial check BH547 (Table 5). The higher grain yield of crosses over quality protein maize BHQPY545 and normal maize BH549 suggests that this trial has a strong chance of identifying the more productive commercial variety for provitamin A maize. This finding is consistent with [7, 22, 34], who found a higher mean grain yield and related traits than the best hybrid check.

L12xL5 showed the lowest mean number of days to anthesis, 77.34 days. On the other hand, BHQPY545 had the highest number of days to anthesis, which was 85.54 days. The average mean of all the hybrids was 82.15 days. L10xL6, L12xL7, L13xL4, L13xL7, and L13xL11 were found to improve DA by 1.79% as compared to the most recent hybrid check, BH549, which had an average number of days to anthesis of 82.55 days. The lowest and highest days to silking (DS) values were observed in L12xL1 and BHQPY545, respectively, which were 78.84 and 87.53. The average mean of all the hybrids was 84.25. L10xL6, L12xL7, L13xL1, L13xL4, L13xL7, and L13xL11 were significantly later in DA, DS, and ASI than BH549. L12XL1 had the shortest anthesis silking interval (0.83 days), while L13XL1 had the longest ASI (3.99 days), with an average mean of 2.1 as shown in Table 4. The ASI, which is the time between anthesis and silking, is an important factor in determining drought tolerance. A smaller mean cross indicates that there are fewer days between the anthesis date and silking date, which is beneficial for optimal seed setting and drought tolerance. On the other hand, a longer ASI can result in less variety of pollen, which increases the chance of incorrect fertilization and crop loss. The results obtained in this study are consistent with the findings reported by [21, 37].

The study revealed that in the case of DA and DS, about 8 and 5 single crosses of provitamin A maize respectively matured significantly earlier than BH549. This information is summarized in Table 4. In other words, the cross L7xL9 had the lowest average number of days to anthesis (71.3 days), while L2xL11 took the longest (83.8 days), with an average mean of 75.3 days across all the crosses. In this experiment, hybrids that mature late can be produced by using crosses with late anthesis and silking as gene sources. In contrast, crosses with shorter days before flowering can be used to create early maturing hybrids. Generally, early maturing hybrids are better suited for areas with a short rainy season to avoid moisture stress during the grain-filling stage or later in the season. In Table 5, it was observed that L2xL11 and L7xL10 had the lowest and highest days to silking (DS) values, respectively, with an average of 75.3 days. L5XL6 and L7xL10 had the shortest anthesis silking, with zero days. On the other hand, around 17 single crossings of provitamin A maize and regular commercial check BH547 demonstrated the longest ASI, with two days, and an average mean of 1. It is possible to use the higher mean values for DA, ASI, and DS to identify a gene that controls late phonological traits. On the other hand, the lower mean values for these traits may indicate a gene responsible for earliness. Early maturing crosses are useful in areas with shorter rainy seasons as they can avoid moisture stress during the grain-filling phase. [34] also identified the earliest and fastest maturing hybrid among the standard checks available so far.

From the two separate trials conducted, it was observed that the tallest plant height (222.57 cm) was obtained from cross L10xL4, while the tallest ear height (243.7 cm) was from cross L9xL10. On the other hand, the shortest plant and ear height were found in cross L12xL10 (175.6 cm) and L2xL11 (140.3 cm) respectively, as shown in Tables 4 & 5. Shorter crosses are desirable for lodging tolerance and the adoption of crucial farming practices, while taller ones are important for harvesting high biomass yields that can be used as animal feed and a source of fuel for poor farmers, according to [5] and Girma et al. (2015). It is a well-known fact in maize selection breeding that certain agronomic characteristics significantly impact crop performance, yield, or quality traits. For instance, [2, 29] have found that opting for shorter plant heights and medium ear positioning can improve lodging resistance and make mechanized agriculture a smoother process. By taking these factors into account, we can make more informed decisions about our breeding program and work towards a more successful harvest.

Table 4. *Hybrid mean performance of grain yield and other agronomic traits of provitamin A maize hybrids and standard checks evaluated by using RCBD design at Bako National Maize Research Center, west Shewa, Ethiopia in 2022.*

Crosses	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	CLR	SLP	RLP	PA	EA	ERP	HCP
L10XL4	7.51	82.15	83.85	1.7	222.57	99	0.44	5.68	3.75	4.24	3.43	-1	2.73	4.05	3.17	9.93
L10XL3	7.99	81.99	84.46	2.47	197.57	91.47	0.46	6.03	3.5	4.58	3.03	2.35	3.51	3.43	1.12	0.7
L10XL6	8.07	83.41	85.02	1.62	201.78	90.07	0.44	4.91	3.15	4.25	-0.47	4.52	4.8	4.39	4.85	5.94
L12XL1	6.65	78.01	78.84	0.83	178.65	73.45	0.41	3.84	3.47	3.81	4.53	9.47	4.13	4.74	1.98	1.19
L12XL2	6.48	81.99	83.46	1.47	184.07	85.97	0.46	2.53	3.5	4.08	3.93	3.55	3.51	3.93	1.12	-2.24
L12XL3	6.98	79.88	82.14	2.26	195.2	86.09	0.44	6.1	5.68	4.52	-2.53	4.8	4.17	4.58	-0.77	2.91
L12XL5	6.44	77.34	79.83	2.48	185.42	73.97	0.4	5.97	3.61	5.68	3.61	-0.37	4.63	4.9	2.79	2.81
L12XL6	7.1	81.53	82.56	1.03	207.04	102.17	0.49	4.78	5.88	5.87	-3.07	5.53	4.69	3.4	-0.01	-2.96
L12XL7	6.59	83.72	85.09	1.37	188.26	85.3	0.46	4.33	8.11	3.7	3.28	3.67	3.88	2.81	0.26	2.41
L12XL10	6.26	82.92	86.57	3.66	175.6	75.77	0.43	3.62	4.73	1.14	3.25	0.95	4.29	3.16	4.74	1.19
L13XL1	6.78	83.54	87.53	3.99	180.2	63.11	0.34	7.26	7.17	4.68	7.63	11.6	5.39	5.71	-0.5	5.44
L13XL3	5.03	82.88	84.42	1.54	178.39	69.66	0.39	3.23	3.49	3.47	11.96	11.96	4.82	5.37	2.1	-0.85
L13XL4	5.09	83.09	85.09	2	194.34	88.25	0.45	2.49	5.84	4.27	14.48	11.59	3.78	4.99	4.42	0.43
L13XL6	6.21	82.03	84.56	2.53	216.54	100.17	0.46	4.78	5.13	4.37	6.38	13.58	3.69	2.9	3.12	-2.96
L13XL7	6.9	84.04	87.03	2.99	211.7	99.11	0.46	4.76	4.42	4.18	2.43	3.3	4.89	5.21	2.62	5.79
L13XL10	7.14	81.92	84.07	2.16	199.6	88.27	0.44	3.62	3.98	1.14	8	7.6	4.29	3.66	1.87	3.97
L13XL11	5.5	83.88	85.92	2.04	184.89	70.16	0.38	4.23	5.99	0.97	6.01	11.26	3.82	3.87	3.59	1.93
L13XL12	7.78	80.59	83.09	2.5	182.34	73.25	0.4	2.49	5.34	6.77	1.78	9.19	1.78	3.99	3.13	0.43
BH 549	6.13	82.55	83.94	1.39	220.12	110.65	0.5	3.59	4.1	1.6	6.39	10.55	2.31	4.21	3.35	-1.62
BH 545	4.79	85.54	87.53	1.99	206.7	94.61	0.45	4.76	5.67	6.18	8.93	3.55	3.89	7.71	7.28	2.66
Maximam	8.07	85.54	87.53	3.99	222.57	110.65	0.5	7.26	8.11	6.77	14.48	13.58	5.39	7.71	7.28	9.93
Minimum	4.79	77.34	78.84	0.83	175.6	63.11	0.34	2.49	3.15	0.97	-3.07	-1	1.78	2.81	-0.77	-2.96
Average	6.57	82.15	84.25	2.1	195.55	86.02	0.44	4.45	4.82	3.98	4.65	6.38	3.95	4.35	2.51	1.85
SE	0.63	0.95	1.25	0.9	7.12	7.25	0.03	1.36	1.47	1	3.24	4.89	0.56	0.91	2.97	2.91

Note: DA=days to anthesis, DS=days to silking, ASI=anthesis silking interval, PH=plant eight, EH=ear height, EPO=ear position, GY=grain yield, GLS= gray leaf spot, TLB=Turcicum leaf blight, CLR=common leaf rust, SLP=stock lodging percentage, RLP= root lodging percentage, PA= plant aspect, EA= ear aspect, ERP= ear rot percentage and HCP= husk cover percentage *and** significant at P<0.05 and P<0.01 respectively.

Table 5. Hybrid mean performance of grain yield and other agronomic traits of provitamin A maize hybrids and standard checks evaluated by using Alpha lattice design at Bako National Maize Research Center, West Shewa, Ethiopia in 2022.

Crosses	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	PA	EA
L1xL2	6.23	73.6	74.4	1	219.2	103.8	0.5	3.2	5.4	3.9	3.5
L1xL3	5.6	75.5	76.2	1	222.1	108.2	0.5	6.3	6.1	4.4	4.1
L1xL4	6.27	75.7	76.8	1	215.7	100.8	0.5	6.5	6.1	4.4	4.3
L1xL5	5.06	75.3	76.1	1	214.5	100.6	0.5	3.4	3.8	4.1	4.5
L1xL6	6.68	75.8	76.8	1	225.3	112.6	0.5	3.1	4.2	2.9	3.5
L1xL7	3.45	80	82	2	223.5	100.8	0.4	5.9	6.8	4.5	5
L1xL8	3.75	77	78	1	209.5	84.3	0.4	4.4	7.5	4.8	5
L1xL9	6.66	73.5	75	2	196.7	116.3	0.6	3.8	4.9	3.8	3.2
L1xL10	5.62	76	76.9	1	207	98.6	0.5	3.3	5.7	3.4	3.7
L1xL11	1.95	78.8	79.9	1	226.1	94.8	0.4	3.4	4.5	4.7	3.9
L1xL12	6.16	74.2	75	1	217.9	109.8	0.5	4.8	6.2	4.9	4.8
L2XL3	6.45	75	76	1	216.7	111.8	0.5	3.6	5.2	4.3	7.2
L2XL4	6.73	76.7	77.7	1	227.7	113.2	0.5	3.1	3.7	3.5	3.2
L2XL5	8.47	76.5	77.4	1	226.5	110.6	0.5	2.1	4	3.7	4.2
L2XL6	7.83	73.5	74.7	1	217.1	111.2	0.6	6.3	7.1	4.4	4.6
L2XL7	4.47	75.8	77.3	2	220.3	109.6	0.5	2.1	4.7	4.2	4.5
L2XL8	5.63	75.6	77.2	2	212.9	108.9	0.5	4.2	4.8	3.9	3.9
L2XL9	6.29	79	80.5	2	221.7	110.8	0.5	2.6	4.4	3.6	3.7
L2XL10	7.64	77.7	79.2	1	224.2	104.2	0.5	2.1	5.2	3	3.7
L2XL11	3.27	83.8	85.3	2	140.3	79.6	0.6	5.3	7.2	5.9	6
L2XL12	4.02	79.5	81.3	2	185.7	81.6	0.4	3.5	5.7	6.1	7.3
L3XL4	6.33	76.6	78.2	2	226.4	105.4	0.5	4.7	6	5.1	3.9
L3XL5	6.16	77.1	78.4	1	225.7	114.3	0.5	3.2	5.9	3.9	3
L3XL6	6.71	77.3	78.9	2	232.6	114.8	0.5	4.1	6.3	4	4.9
L3XL7	7.07	75.5	77.3	2	236.7	116.6	0.5	3.5	5.4	3.9	4.3
L3XL8	5.96	75.6	76.9	1	237.2	108.8	0.5	5.7	7.4	4.1	4
L3XL9	7.39	75.7	76.7	1	237.7	112.2	0.5	6.4	7.5	3.7	4.2
L3XL10	7.27	77.8	80	2	228.9	120.8	0.5	3.3	4.2	3.6	4.9
L3XL11	6.17	73.5	74.6	1	225.9	97.8	0.4	3.7	6.8	4.3	4.1
L3XL12	6.77	75.5	76.3	1	208.2	85.1	0.4	3	5.9	4.1	4.3
L4XL5	4.97	72.8	74.3	2	218.3	100.1	0.4	5.1	6	4.4	4
L4XL6	5.97	77	77.7	1	218.6	101.2	0.5	5.8	6.1	4.1	4.6
L4XL7	5.22	72	73.5	2	206	90.8	0.4	4.4	7.8	4.2	5.5
L4XL8	7.01	72.8	74	1	223.4	104.3	0.5	5.8	7.4	4.9	5.9
L4XL9	5.95	74.4	75.7	1	196.4	95.4	0.5	4.2	6.1	4.9	4.7
L4XL10	5.72	73.2	74.8	2	215.2	96.3	0.4	6.5	7.1	5.9	6.8
L4XL11	5.07	72	73	1	224.2	95.3	0.5	3.3	5.2	5.6	6.2

Crosses	GY	DA	DS	ASI	PH	EH	EPO	GLS	TLB	PA	EA
L4XL12	6.32	73.8	75	1	230.4	105.8	0.5	5.3	5.7	5.9	5.4
L5XL6	1.75	75.8	75.4	0	211.1	87.8	0.4	4.1	4.3	4.7	5.9
L5XL7	6.47	73.2	74	1	221.4	89.8	0.4	4.3	5.9	4.2	4.8
L5XL8	7.23	74	75	1	217	97.8	0.4	4.4	5	4	5.5
L5XL9	8.76	72.3	73.3	1	228.3	102.6	0.4	3.6	5.5	3.9	4.5
L5XL10	7.37	78.9	81.2	2	236.4	113.9	0.5	3.5	4.6	4.4	4.2
L5XL11	7.79	71.8	73	1	231.9	113.3	0.5	5.3	6.2	3.6	5.4
L5XL12	5.81	71.4	73.2	2	218.9	90.4	0.4	6	6.3	4.7	6.2
L6xL7	5.89	73.7	74.7	1	197.7	84.2	0.4	4.9	5.7	4.7	4.7
L6xL8	6.39	73.5	74.6	1	206.4	93.8	0.4	3.7	5.6	4	4.1
L6xL9	6.16	77	78.2	1	204.6	89.7	0.5	3.8	5.9	4.1	4.1
L6xL10	5.27	76.2	77	1	212.4	88.3	0.4	2.6	5.4	5.4	4.8
L6xL11	7.24	72.1	73.2	1	201.4	81.4	0.4	6.9	6	4.4	4.9
L6xL12	6.77	75	76.1	1	213.9	98.3	0.4	5.2	6.1	4.5	5.6
L7XL8	5.02	74.2	75.5	1	189.4	84.3	0.4	3.3	3.7	4.4	6.8
L7XL9	5.6	71.3	73.1	2	219.5	96.6	0.4	4.4	6.3	4.1	4
L7XL10	5.83	71.7	72	0	194.4	83.8	0.4	4.3	5.9	4.7	5.8
L7XL11	5.88	72.8	73.9	1	203.1	87.3	0.4	4.1	6.8	5	5.9
L7XL12	4.47	72.8	73.6	1	211.5	101.6	0.5	2.9	4.8	3.6	4
L8xL9	7.6	74.5	75.4	1	229	116.6	0.5	3.6	6	3.7	4.2
L8xL10	7.51	75.4	76.2	1	228.9	113.9	0.5	3.5	5.1	4.4	4.7
L8xL11	6.94	77.8	79.4	2	234.6	124.8	0.6	3.1	5.3	3	3.4
L8xL12	9.11	75.3	76.1	1	237	118.6	0.5	2.4	4.3	3.1	4
L9xL10	6.03	75.6	76.9	1	234.7	119.8	0.5	3.7	5.6	3.9	5.5
L9xL11	7.56	78.2	79.3	1	241.7	128.8	0.5	2.2	4.6	4.9	6.8
L9xL12	7.63	75.6	76.7	1	229.9	117.4	0.5	4.4	4.3	3.9	4.4
L10XL11	6.26	73	74.1	1	209.4	104.3	0.5	5.2	5.8	4.3	5.1
L10XL12	6.92	71.5	72.3	1	232.7	107.6	0.4	3	5.7	3.9	5.3
L11XL12	6.52	71.7	72.8	1	226.2	109.3	0.5	4.2	6.3	5.7	7.3
BH546	7.11	79.5	80.9	1	215	97.6	0.4	2.6	4.5	4.4	5.7
BH547	8.95	82.7	84.3	2	223.2	121.8	0.5	3	4.8	4.7	4.3
Maximum	9.11	83.8	85.3	2	241.7	128.8	0.6	6.9	7.8	6.1	7.3
Minimum	1.75	71.3	72	0	140.3	79.6	0.4	2.1	3.7	2.9	3
Average	6.21	75.3	76.5	1	218	103	0.5	4.1	5.6	4.3	4.8
SE	0.78	1.2	1.3	0	8.6	6.5	0	0.7	0.9	0.5	0.6

Note: DA=days to anthesis, DS=days to silking, ASI=anthesis silking interval, PH=plant eight, EH=ear height, EPO=ear position, GY=grain yield, GLS= gray leaf spot, TLB=Turcicum leaf blight, PA= plant aspect, and EA= rear aspect.

3.3. Standard Heterosis of Provitamin a Maize Genotypes

The values of standard heterosis estimated for grain yield and other traits across locations are presented in Tables 6 & 7.

The average heterosis of crossings over the two standard checks (BH549 and BHQPY545) for grain yield varied from -17.94% to 31.65% and 5.01% to 68.48%, respectively. On the other hand, three hybrids had a positive and considerably higher grain yield than BH549, and thirteen crosses had a positive and significantly higher grain yield than BHQPY545 (Table 6). Furthermore, according to Table 7, for grain yield, nine out of twelve crosses exhibited positive and significant advantages over the standard checks BH546 and BH547, with ranges of (-75.4% to 28.13%) and (-80.45% to 1.79%), respectively. About ten single crosses showed negative significance over BH546 and almost all of the single crosses showed negative significance at P<0.01 and P<0.05 over BH547. To maximize heterosis and increase maize grain yield, crosses that demonstrated positive results and a greater grain yield than the commercial standard checks are preferred. Additionally, hybrids that outperform checks may be employed in commercial production. On the other hand, the crosses indicated a less promising yield than the commercial checks, with negative and non-significant differences. Positive heterosis is preferred since it shows a higher yield compared to the current standard check. Many academics, including [5, 13, 23, 24], have reported the presence of positive and substantial standard heterosis for grain yield. They have also identified significant positive and negative values of standard heterosis for grain yield.

For days to anthesis and days to silking crosses, most single crosses showed negative and significant differences that imply the crosses would take shorter days to anthesis and silking than the commercial varieties or it implies a desirable direction for both the days to anthesis and silking than the check. On the contrary, the crosses L13xL1 and L13xL7 showed positive and significant over BH549 for days to silking while L2xL11 showed positive and significant over BH546 for both days to anthesis and days to silking. Positive and significant standard heterosis for days to silking indicates that late silking is directly correlated with late maturity, and the reverse holds for the negative heterosis. Finally, for DA and DS apprehensive; the desirable negative and significant SH was observed for some cross combinations over a high-yielding hybrid check and desirable direction for traits DA and DS over BH546 and BHQPY545 (Tables 6 and 7). Such genotypes identified for their earlier maturity could be used in multiple cropping systems and to increase efficient land and water use. Significant heterosis for such agronomic traits has been reported by various investigators including [6, 7, 21, 22, 37].

The standard heterosis estimates of the crossings over the two commercial checks for plant height, BH549, and BHQPY545, respectively, varied from -20.23% to 1.11 % and -15.05% to -6.35% (Table 6). In this experiment, most comprising single cross-plant heights were significantly lower than that of the commercial checks of BH549, BHQPY545, BH546, and BH547 (Tables 6 & 7). Negative heterosis for plant height often indicates that the hybrids will resist lodging and mature earlier, which is favorable for generating short-statured hybrids. Conversely, crosses with noticeably taller plants yielded more grain; this could be explained by an extensive accumulation of photosynthetic products throughout grain filling. The findings of [23, 24, 30] were in agreement with these results. Conversely, short plant and ear heights are chosen for ease of mechanical operations and to reduce lodging problems with maize. As a result, the variation seen in the tested crosses may aid in the development of these qualities.

Table 6. *Estimates of standard heterosis (SH) for grain yield and other agronomic traits of provitamin A maize hybrids evaluated by using RCBD design at Bako National Maize Research Center, west Shewa, Ethiopia in 2022.*

	Grain yield (t/hec)		Days to Anthesis		Days to Silking		Plant Height		Ear Height	
Crosses	SH		SH		SH		SH		SH	
	BH549	BH545	BH549	BH545	BH549	BH545	BH549	BH545	BH549	BH545
L10XL4	22.51	56.78**	-0.48	-3.96**	-0.11	-4.2**	1.11	7.68*	-10.53	4.64
L10XL3	30.34*	66.81**	-0.68	-4.15**	0.62	-3.51*	-10.24**	-4.42	-17.33*	-3.32
L10XL6	31.65*	68.48**	1.04	-2.49	1.29	-2.87	-8.33*	-2.38	-18.6*	-4.8
L12XL1	8.48	38.83*	-5.5**	-8.8**	-6.1**	-9.93**	-18.84**	-13.57**	-33.62**	-22.37*
L12XL2	5.71	35.28*	-0.68	-4.15**	-0.57	-4.65**	-16.38**	-10.95**	-22.3**	-9.13
L12XL3	13.87	45.72**	-3.23*	-6.62**	-2.14	-6.16**	-11.32**	-5.56	-22.2**	-9.01
L12XL5	5.06	34.45*	-6.3**	-9.59**	-4.9**	-8.8**	-15.76**	-10.3**	-33.15**	-21.82*

Crosses	Grain yield (t/hec) SH		Days to Anthesis SH		Days to Silking SH		Plant Height SH		Ear Height SH	
	BH549	BH545	BH549	BH545	BH549	BH545	BH549	BH545	BH549	BH545
L12XL6	15.82	48.23**	-1.24	-4.69**	-1.64	-5.68**	-5.94	0.16	-7.66	7.99
L12XL7	7.5	37.58*	1.42	-2.13	1.37	-2.79	-14.47**	-8.92*	-22.91**	-9.84
L12XL10	2.12	30.69	0.45	-3.06*	3.13	-1.1	-20.23**	-15.05**	-31.52**	-19.91*
L13XL1	10.6	41.54*	1.2	-2.34	4.28*	0	-18.14**	-12.82**	-42.96**	-33.3**
L13XL3	-17.94	5.01	0.4	-3.11*	0.57	-3.55*	-18.96**	-13.7**	-37.04**	-26.4**
L13XL4	-16.97	6.26	0.65	-2.86*	1.37	-2.79	-11.71**	-5.98	-20.24**	-6.72
L13XL6	1.31	29.65	-0.63	-4.1**	0.74	-3.39*	-1.63	4.76	-9.47	5.88
L13XL7	12.56	44.05**	1.8	-1.75	3.68*	-0.57	-3.83	2.42	-10.43	4.76
L13XL10	16.48	49.06**	-0.76	-4.23**	0.15	-3.95*	-9.32*	-3.43	-20.23**	-6.7
L13XL11	-10.28	14.82	1.61	-1.94	2.36	-1.84	-16**	-10.55**	-36.59**	-25.8**
L13XL12	26.92*	62.42**	-2.37	-5.79**	-1.01	-5.07**	-17.16**	-11.79**	-33.8**	-22.58*
Maximum	31.65	68.48	1.8	-1.75	4.28	0	1.11	7.68	-7.66	7.99
Minimum	-17.94	5.01	-6.31	-9.59	-6.08	-9.93	-20.23	-15.05	-42.96	-33.29
Average	9.21	39.76	-0.74	-4.21	0.17	-3.94	-12.06	-6.35	-23.92	-11.02
SE	0.54		0.82		0.99		5.62		5.72	

Note: DA=days to anthesis, DS=days to silking, PH=plant eight, EH=ear height, GY=grain yield, *and** significant at P<0.05 and P<0.01 respectively.

Table 7. *Estimates of standard heterosis (SH) for grain yield and other agronomic traits of provitamin A maize hybrids evaluated by using Alpha lattice design at Bako National Maize Research Center, west Shewa, Ethiopia in 2022.*

Crosses	Grain yield (t/hec) SH		Days to Anthesis SH		Days to Silking SH		Plant Height SH		Ear Height SH	
	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547
L1xL2	-12.38	-30.39*	-3.63**	-11**	-8.03**	-11.7**	1.95	-1.79	6.35	-14.78*
L1xL3	-21.24	-37.4**	-2.46*	-8.71**	-5.81**	-9.61**	3.3	-0.49	10.86	-11.17
L1xL4	-11.81	-29.94*	-2.34*	-8.46**	-5.07*	-8.9**	0.33	-3.36	3.28	-17.24*
L1xL5	-28.83	-43.5**	-2.58*	-8.95**	-5.93**	-9.73**	-0.23	-3.9	3.07	-17.41*
L1xL6	-6.05	-25.36*	-2.28*	-8.34**	-5.07*	-8.9**	4.79	0.94	15.37	-7.55
L1xL7	-51.48**	-61.5**	0.31	-3.26	1.36	-2.73	3.95	0.13	3.28	-17.24*
L1xL8	-47.26**	-58.1**	-1.54	-6.89**	-3.58	-7.47**	-2.56	-6.14	-13.63	-30.8**
L1xL9	-6.33	-25.59*	-3.69**	-11.1**	-7.29**	-11.1**	-8.51	-11.87*	19.16*	-4.52
L1xL10	-20.96	-37.2**	-2.15*	-8.1**	-4.94*	-8.78**	-3.72	-7.26	1.02	-19.1**
L1xL11	-72.6**	-78.2**	-0.43	-4.72*	-1.24	-5.22*	5.16	1.3	-2.87	-22.2**
L1xL12	-13.36	-31.2**	-3.26**	-10.3**	-7.29**	-11.1**	1.35	-2.37	12.5	-9.85

Crosses	Grain yield (t/hec) SH		Days to Anthesis SH		Days to Silking SH		Plant Height SH		Ear Height SH	
	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547
L2XL3	-9.28	-27.93*	-2.77**	-9.31**	-6.06**	-9.85**	0.79	-2.91	14.55	-8.21
L2XL4	-5.34	-24.8*	-1.72	-7.26**	-3.96	-7.83**	5.91	2.02	15.98	-7.06
L2XL5	19.13	-5.36	-1.85	-7.5**	-4.33*	-8.19**	5.35	1.48	13.32	-9.2
L2XL6	10.13	-12.51	-3.69**	-11.1**	-7.66**	-11.4**	0.98	-2.73	13.93	-8.7
L2XL7	-37.13*	-50.1**	-2.28*	-8.34**	-4.45*	-8.3**	2.47	-1.3	12.3	-10.02
L2XL8	-20.82	-37.1**	-2.4*	-8.59**	-4.57*	-8.42**	-0.98	-4.61	11.58	-10.59
L2XL9	-11.53	-29.72*	-0.31	-4.47*	-0.49	-4.51*	3.12	-0.67	13.52	-9.03
L2XL10	7.45	-14.64	-1.11	-6.05**	-2.1	-6.05**	4.28	0.45	6.76	-14.45*
L2XL11	-54.01**	-63.5**	2.65**	1.33	5.44*	1.19	-34.7**	-37.2**	-18.44*	-34.7**
L2XL12	-43.46**	-55.1**	0	-3.87	0.49	-3.56	-13.63*	-16.8**	-16.39	-33**
L3XL4	-10.97	-29.27*	-1.78	-7.38**	-3.34	-7.24**	5.3	1.43	7.99	-13.46
L3XL5	-13.36	-31.2**	-1.48	-6.77**	-3.09	-7**	4.98	1.12	17.11	-6.16
L3XL6	-5.63	-25.03*	-1.35	-6.53**	-2.47	-6.41**	8.19	4.21	17.62	-5.75
L3XL7	-0.56	-21.01	-2.46*	-8.71**	-4.45*	-8.3**	10.09	6.05	19.47*	-4.27
L3XL8	-16.17	-33.4**	-2.4*	-8.59**	-4.94*	-8.78**	10.33	6.27	11.48	-10.67
L3XL9	3.94	-17.43	-2.34*	-8.46**	-5.19*	-9.02**	10.56	6.5	14.96	-7.88
L3XL10	2.25	-18.77	-1.05	-5.93**	-1.11	-5.1*	6.47	2.55	23.77**	-0.82
L3XL11	-13.22	-31.1**	-3.69**	-11.1**	-7.79**	-11.5**	5.07	1.21	0.2	-19.7**
L3XL12	-4.78	-24.4*	-2.46*	-8.71**	-5.69**	-9.49**	-3.16	-6.72	-12.81	-30.13**
L4XL5	-30.1*	-44.47**	-4.12**	-11.97**	-8.16**	-11.86**	1.53	-2.2	2.56	-17.82*
L4XL6	-16.03	-33.3**	-1.54	-6.89**	-3.96	-7.83**	1.67	-2.06	3.69	-16.91*
L4XL7	-26.58	-41.68**	-4.62**	-12.94**	-9.15**	-12.81**	-4.19	-7.71	-6.97	-25.45**
L4XL8	-1.41	-21.68	-4.12**	-11.97**	-8.53**	-12.22**	3.91	0.09	6.86	-14.37*
L4XL9	-16.32	-33.52**	-3.14**	-10.04**	-6.43**	-10.2**	-8.65	-12.01*	-2.25	-21.67**
L4XL10	-19.55	-36.09**	-3.88**	-11.49**	-7.54**	-11.27**	0.09	-3.58	-1.33	-20.94**
L4XL11	-28.69	-43.35**	-4.62**	-12.94**	-9.77**	-13.4**	4.28	0.45	-2.36	-21.76**
L4XL12	-11.11	-29.39*	-3.51**	-10.76**	-7.29**	-11.03**	7.16	3.23	8.4	-13.14
L5XL6	-75.4**	-80.45**	-2.28*	-8.34**	-6.8**	-10.56**	-1.81	-5.42	-10.04	-27.91**
L5XL7	-9	-27.71*	-3.88**	-11.49**	-8.53**	-12.2**	2.98	-0.81	-7.99	-26.27**
L5XL8	1.69	-19.22	-3.39**	-10.52**	-7.29**	-11.03**	0.93	-2.78	0.2	-19.7**
L5XL9	23.21	-2.12	-4.43**	-12.58**	-9.39**	-13.05**	6.19	2.28	5.12	-15.76*
L5XL10	3.66	-17.65	-0.37	-4.59*	0.37	-3.68	9.95	5.91	16.7	-6.49
L5XL11	9.56	-12.96	-4.74**	-13.18**	-9.77**	-13.4**	7.86	3.9	16.09	-6.98
L5XL12	-18.28	-35.08**	-4.99**	-13.66**	-9.52**	-13.17**	1.81	-1.93	-7.38	-25.78**
L6xL7	-17.16	-34.19**	-3.57**	-10.88**	-7.66**	-11.39**	-8.05	-11.42*	-13.73	-30.87**
L6xL8	-10.13	-28.6*	-3.69**	-11.12**	-7.79**	-11.51**	-4	-7.53	-3.89	-22.99**

Crosses	Grain yield (t/hec) SH		Days to Anthesis SH		Days to Silking SH		Plant Height SH		Ear Height SH	
	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547	BH546	BH547
L6xL9	-13.36	-31.17**	-1.54	-6.89**	-3.34	-7.24**	-4.84	-8.33	-8.09	-26.35**
L6xL10	-25.88	-41.12**	-2.03*	-7.86**	-4.82*	-8.66**	-1.21	-4.84	-9.53	-27.5**
L6xL11	1.83	-19.11	-4.55**	-12.82**	-9.52**	-13.17**	-6.33	-9.77	-16.6	-33.17**
L6xL12	-4.78	-24.36*	-2.77**	-9.31**	-5.93**	-9.73**	-0.51	-4.17	0.72	-19.29**
L7XL8	-29.4*	-43.91**	-3.26**	-10.28**	-6.67**	-10.44**	-11.91*	-15.14**	-13.63	-30.79**
L7XL9	-21.24	-37.43**	-5.05**	-13.78**	-9.64**	-13.29**	2.09	-1.66	-1.02	-20.69**
L7XL10	-18	-34.86**	-4.8**	-13.3**	-11**	-14.59**	-9.58	-12.9*	-14.14	-31.2**
L7XL11	-17.3	-34.3**	-4.12**	-11.97**	-8.65**	-12.34**	-5.53	-9.01	-10.55	-28.33**
L7XL12	-37.13*	-50.06**	-4.12**	-11.97**	-9.02**	-12.69**	-1.63	-5.24	4.1	-16.58*
L8xL9	6.89	-15.08	-3.08**	-9.92**	-6.8**	-10.56**	6.51	2.6	19.47*	-4.27
L8xL10	5.63	-16.09	-2.52*	-8.83**	-5.81**	-9.61**	6.47	2.55	16.7	-6.49
L8xL11	-2.39	-22.46	-1.05	-5.93**	-1.85	-5.81**	9.12	5.11	27.87**	2.46
L8xL12	28.13	1.79	-2.58*	-8.95**	-5.93**	-9.73**	10.23	6.18	21.52*	-2.63
L9xL10	-15.19	-32.63**	-2.4*	-8.59**	-4.94*	-8.78**	9.16	5.15	22.75*	-1.64
L9xL11	6.33	-15.53	-0.8	-5.44**	-1.98	-5.93**	12.42*	8.29	31.97**	5.75
L9xL12	7.31	-14.75	-2.4*	-8.59**	-5.19*	-9.02**	6.93	3	20.29*	-3.61
L10XL11	-11.95	-30.06*	-4**	-11.73**	-8.41**	-12.1**	-2.6	-6.18	6.86	-14.37*
L10XL12	-2.67	-22.68	-4.92**	-13.54**	-10.63**	-14.23**	8.23	4.26	10.25	-11.66
L11XL12	-8.3	-27.15*	-4.8**	-13.3**	-10.01**	-13.64**	5.21	1.34	11.99	-10.26
Maximum	28.13	1.79	2.65	1.33	5.44	1.19	12.42	8.29	31.97	5.75
Minimum	-75.4	-80.45	-5.05	-13.78	-11	-14.59	-34.74	-37.14	-18.44	-34.65
Average	-13.47	-31.26	-2.7	-9.18	-5.7	-9.5	1.38	-2.34	5.3	-15.62
SE	0.74		1.15		1.22		8.23		6.19	

Note: DA=days to anthesis, DS=days to silking, PH=plant eight, EH=ear height, GY=grain yield, *and** significant at P<0.05 and P<0.01 respectively

4. Conclusions

The extensive extent of both directions of standard heterosis over commercial checks used to conduct these tests indicates the presence of genetic variability, as evidenced by the significant differences found among genotypes for grain yield and yield components of features. Because the undesirable heterosis of new single crosses surpasses commercial inspections, it appears that one family's genes are responsible for the heterosis, with untraceable outcomes. The advantage of conventional heterosis is that it allows both desired and undesirable directions to define the families of the crosses and select the crosses for commercial or breeding purposes. Grain yield in this investigation displayed positive and significant heterosis when compared to commercial checks, confirming that the crosses can be chosen for the product. Furthermore, because their parents supply crosses with highly desirable genes, they can be used in recurrent breeding to expedite genetic gain. In this study, parameters such as days to anthesis and days to silking showed negative and significant heterosis among commercial checks. This implies that the crosses mature faster than commercial checks, which improves grain yield and the production cycle.

In general, assessing perse and hybrid performance in maize breeding tasks tends to enhance maize yield and productivity. Studying the standard heterosis of traits in conventional breeding is especially important because the positive and negative direction for specific traits implies basic concepts to identify genotype characteristics such as production, foliar disease reaction, and other environmental factors. For grain yield and yield components, positive standard heterosis encourages the popularity of the specific genotype, but for foliar diseases reactivity, days to anthesis and silking, tallness or shortness, root and stock lodging, negative direction Standard heterosis reflects the acceptability of a certain genotype, which provides valuable principles for selection decisions in maize breeding. More effective and efficient investigation into provitamin A maize varieties should be continued using both conventional and molecular breeding, as provitamin A maize genotypes have only recently become known in sub-Saharan Africa, mostly in Ethiopia, and there are plenty of scenarios in which malnutrition arises in areas where maize is dominantly cultivated.

Abbreviations

BNMRC	Bako National Maize Research Center
EIAR	Ethiopian Institute of Agricultural Research
SH	Standard Heterosis
t/ha	Tone Per Hectare
SE	Standard Error

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Author Contributions

Lemi Yadesa: Conceptualization, Data curation, Formal Analysis, Writing – original draft

Belay Garoma: Conceptualization, Methodology, Visualization, Writing – review & editing

Gemechu Aseffa: Investigation, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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