World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Analysis of the combining ability of temperate and tropical maize (*Zea mays* L.) lines in Burkina Faso

Siaka TIAMA [1, 2, *], Abdalla DAO [2], Togue Saturnin COULIBALY [2], Jacob SANOU [3] and Mahamadou SAWADOGO [1]

[1] *Department of Plant Biology and Physiology, Biosciences Laboratory, Joseph KI-ZERBO University, 09 BP 1635, Ouagadougou 09, Ouagadougou, Burkina Faso.*

[2] *Plant Production Department, Institute of Environment and Agricultural Research, 01 BP 910, Bobo Dioulasso 01, Bobo Dioulasso, Burkina Faso.*

[3] *Department of Science and Technology, New Dawn University, 01 BP 234, Bobo Dioulasso 01, Bobo Dioulasso, Burkina Faso.*

World Journal of Advanced Research and Reviews, 2025, 28(01), 215-226

Publication history: Received on 21 August 2025; revised on 30 September 2025; accepted on 03 October 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.1.3401

Abstract

The development of high-yielding maize varieties requires an adequate choice of potential parents for hybrid development. New yellow inbred lines were used to generate new hybrids through a half-diallel design in 2021. The new hybrids were evaluated in three environments in 2022 and 2023, using the alpha latice design with three replicates. Observations focused on grain yield and its components. The variability within hybrids was determined and the general and specific combining ability (GCA and SCA) of the inbred lines were estimated. The results showed high variability ($P < 0.001$) within the hybrids, between study environments and their interaction for the majority of traits assessed. In addition, the GCA and SCA variances showed significant differences for all the traits assessed. This is an indication of the presence of both additive and non-additive gene effects in the inheritance of the traits. The inbred lines PI601561, ELN45-1-1-1, FBML10 and TZEI146 lines recorded positive and significant GCA effects for yield and yield-related traits revealing that these lines could be potential inbred lines for high yielding hybrids development as well as new inbred lines extraction. These lines could be used as testers for future studies. The results also showed that hybrids such as FBML10 x PI601009, ELN45-1-1-1 x PI601686, TZEI17 x PI601191, TZEI146 x PI600954, etc. showed positive and significant SCA effects for the grain yield trait. These hybrids could be used to develop three-way and two-way hybrids to improve maize production.

Keywords: Burkina Faso; Combining ability; Hybrids; Lines; Maize

1. Introduction

Agriculture plays an essential role in the development and food security of African countries. In Burkina Faso, it employs nearly 85% of the total population and contributes 35% of the gross domestic product (GDP) [1]. The sector is dominated by the production of cereals, which play an important role in human and animal nutrition [2]. Among these cereals, maize is one of the staple food. Its production continues to grow, as it finds multiple applications in the fields of human food, livestock breeding and others [3]. Its production has risen from 1700127 tons in 2018 to 1810276 tons in 2023. It has thus become the leading cereal in terms of production [4]. The success of this cereal could be explained by its high natural yield potential compared with other cereals, as well as by the multiple efforts made by research institutes to create new varieties with high yield potential and adapted to the country's conditions.

* Corresponding author: Siaka TIAMA

Breeding programs have led to the development of several high-performance hybrid varieties. Despite the existence of these new varieties, the production is still low compared to the demand in multiple sectors. To achieve this, breeding programs should continually create new high-performance hybrids to meet the demand.

In addition, information on genetic diversity is also very important for any breeding program, as it enables genetic material to be characterized and assigned to different heterotic groups [5]. Mean performance is one of the most important criteria for evaluating genotypes. Thus, the use of temperate lines in combination with tropical lines would make it possible to introduce new genes into the creation of hybrids. According to [6], it is essential in any breeding program to know the importance of the value of a given trait for the transmission to the progeny of all the favorable genes involved in the expression of this trait during a cross. Knowledge of the combining abilities of these parental lines is essential to generate reliable information and enable breeders to choose representative parents for hybrid development planning [7]. Moreover, it is important to know the mode of inheritance for given before choosing a selection method. Thus, when developing new varieties, the choice of selection methodology is decisive in the action of the genes. Combining ability analysis is a powerful tool for identifying lines for crosses, enabling efficient exploitation of hybrid vigor, but also for identifying high-performance hybrids for future breeding [8].

The objectives of this study were to (i) determine the general and specific combining ability (GCA and SCA) of grain yield and its components for the parental inbred lines, (ii) study the mode of action of genes in the transmission of these traits and (iii) select lines with favorable GCA and hybrids wth favorable SCA effects for desired traits for the development of new high-yielding hybrids.

2. Materials and methods

2.1. Plant material

The study material consisted of 78 single yellow hybrids (Table 1) derived from half-diallel crosses of thirteen temperate and tropical lines. These parental lines were sourced from three research centers namely the Institute of Environment and Agricultural Research (INERA), the International Institute of Tropical Agriculture (IITA) and the North Central Regional Plant Introduction Station (NCRPIS).

Table 1 List of plant material evaluated

N°	Hybrids	N°	Hybrids	N°	Hybrids
1	PI601561 x PI601686	27	PI601191 x PI601575	53	PI547090 x TZEI146
2	PI601561 x PI601191	28	PI601191 x FBML10	54	PI547090 x TZEI10
3	PI601561 x PI600954	29	PI601191 x TZEI146	55	PI547090 x TZI18
4	PI601561 x PI601009	30	PI601191 x TZEI10	56	PI547090 x TZEI17
5	PI601561 x PI547090	31	PI601191 x TZI18	57	PI547090 x ELN45-1-1-1
6	PI601561 x PI601575	32	PI601191 x TZEI17	58	PI601575 x FBML10
7	PI601561 x FBML10	33	PI601191 x ELN45-1-1-1	59	PI601575 x TZEI146
8	PI601561 x TZEI146	34	PI600954 x PI601009	60	PI601575 x TZEI10
9	PI601561 x TZEI10	35	PI600954 x PI547090	61	PI601575 x TZI18
10	PI601561 x TZI18	36	PI600954 x PI601575	62	PI601575 x TZEI17
11	PI601561 x TZEI17	37	PI600954 x FBML10	63	PI601575 x ELN45-1-1-1
12	PI601561 x ELN45-1-1-1	38	PI600954 x TZEI146	64	FBML10 x TZEI146
13	PI601686 x PI601191	39	PI600954 x TZEI10	65	FBML10 x TZEI10
14	PI601686 x PI600954	40	PI600954 x TZI18	66	FBML10 x TZI18
15	PI601686 x PI601009	41	PI600954 x TZEI17	67	FBML10 x TZEI17
16	PI601686 x PI547090	42	PI600954 x ELN45-1-1-1	68	FBML10 x ELN45-1-1-1

17	PI601686 x PI601575	43	PI601009 x PI547090	69	TZEI146 x TZEI10
18	PI601686 x FBML10	44	PI601009 x PI601575	70	TZEI146 x TZI18
19	PI601686 x TZEI146	45	PI601009 x FBML10	71	TZEI146 x TZEI17
20	PI601686 x TZEI10	46	PI601009 x TZEI146	72	TZEI146 x ELN45-1-1-1
21	PI601686 x TZI18	47	PI601009 x TZEI10	73	TZEI10 x TZI18
22	PI601686 x TZEI17	48	PI601009 x TZI18	74	TZEI10 x TZEI17
23	PI601686 x ELN45-1-1-1	49	PI601009 x TZEI17	75	TZEI10 x ELN45-1-1-1
24	PI601191 x PI600954	50	PI601009 x ELN45-1-1-1	76	TZI18 x TZEI17
25	PI601191 x PI601009	51	PI547090 x PI601575	77	TZI18 x ELN45-1-1-1
26	PI601191 x PI547090	52	PI547090 x FBML10	78	TZEI17 x ELN45-1-1-1

2.2. Study sites

The study was conducted across two locations in 2022 and 2023, namely Vina and Bama at Burkina Faso (Figure 1). Vina is located in Tuy province at 130 km from Bobo Dioulasso at 11°34’ north latitude and 3°24’ west longitude, at an altitude of between 300 and 400 meters. In this location, hybrids were evaluated during rainy season from june to september without supplementary irrigation. The second location Bama in Kou valley is situated at 25 km from Bobo-Dioulasso. The experimentation was conducted in INERA experiment sites. This area is located at 10°20’ north latitude, 4°20’ west longitude, 450 m above sea level [9]. The hybrids were assessed during rainy season with supplementary irrigation at the needs from july to september and during dry season from november to march. During the dry season, the water was supplied by gravity irrigation. Cumulative rainfall in both years exceeded 1,000 mm. Ean temperatures ranging from 23°C to 34°C [10].

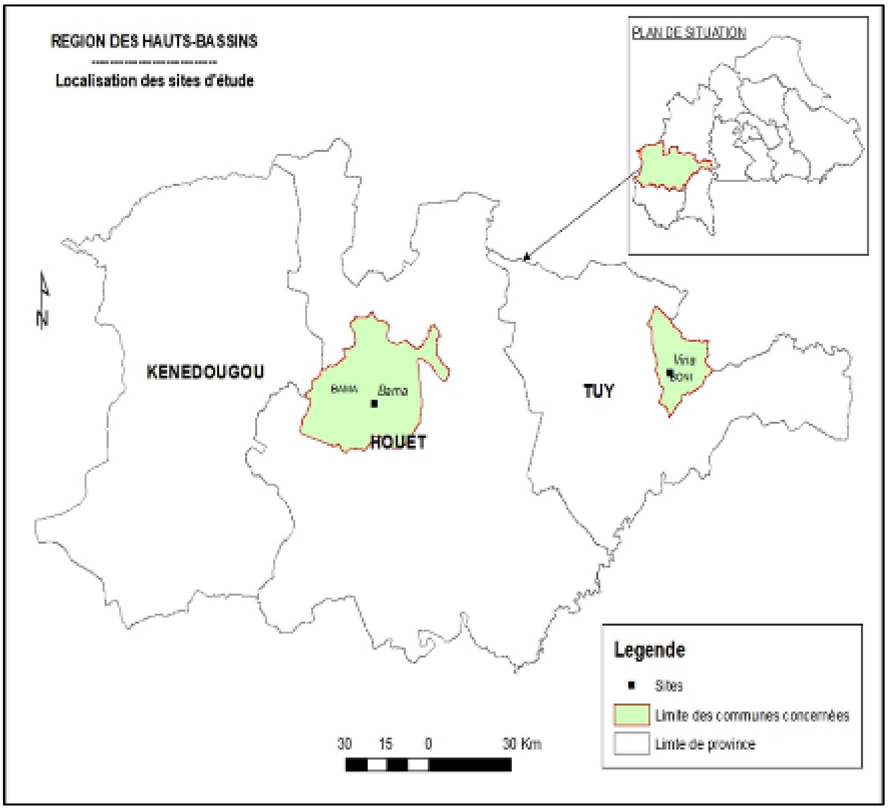


Figure 1 Representation of study sites

2.3. Methods

2.3.1. Experimental design

The seventy-eight hybrids obtained were evaluated using the *6 x 13* alpha lattice design with three replications in three different environments over two years. The plot size was a single 5 m line. The spacing between the holes was 0.4 m while between lines 0.80 m.

2.3.2. Trial management

Organic matter (compost) was applied at a rate of 5 tons per hectare at the time of sowing in each trial. Weeding was carried out as required. Fertilization (NPK 14-23-14) was supplied at 15th day after sowing (DAS) at the rate of 300 kg/ha. Urea 46 was used for top-dressing at the rate 100 kg/ha at 30 day after sowing and 50 kg/ha at 45 day after sowing. The herbicide “Glyphosate 360 g/L” combined with the pre-emergence herbicide “Atrazine 500 g/L” was used to control weeds. In addition, Emamectin benzoate (50 g/kg) was used to control armyworms and locusts as soon as their first symptoms appeared.

2.3.3. Data collection

Observations werefocused on grain yield and its components as described below:

- Grain yield (GY) is the estimate of the variety's production potential based on the weight of harvested ears and grains, and the relative humidity in the study plot. This grain yield is calculated using the following formula:

$$GY = [FW \times (GSW/ESW) \times [(100-GM) / 85] \times (62500/NP)]$$

Where GY= grain weight (kg/ha); FW = Field weight (kg); GSW = grain sample weight (kg); ESW = ears sample weight (kg); GM = grain moisture; NP = number of plants.

- Ear diameter (ED) is the average diameter of ten ears from each useful plot in millimeter.
- Ear length (EL) is the measurement in centimeter of the length of the ear samples harvested per useful plot.
- Number of rows (NR) was obtained by counting the number of rows of grains in the ear.
- Number of grains per row (NGR) was obtained by counting the number of grains in each row.

2.3.4. Statistical analysis

The data collected was entered, organized and processed using Microsoft Excel version 2016 spreadsheet software. Data processing initially consisted of considering all plots with a plant density at harvest (DH) of less than 30% as missing data. In addition, the difference between the highest and lowest yields of the three replicates was calculated for each genotype studied. If the yield of a replicate was lower than this difference, then the yield value for that plot was deleted and considered missing data. A correlation test between the variables studied was carried out using R 4.2.1 software to determine the nature of the relationship between the variables. In addition, the measured variables were subjected to an analysis of variance (ANOVA) using AGD-R 5.1 software. An additive model was used to determine the variability within the study population for all the traits following the formula:

$$Yij = \mu + Gi + Bi + \varepsilon ij$$

where Yij = observed value of genotype i on block j, μ = overall mean of the experiment, Gi = effect of genotype i, Bj = effect of block j and εij = effect due to experimental error.

For the analysis of variance, each combination year by location was considered as an environment. Then six environments were involved in the data analysis.

The factors “environment, replicates and blocks” were considered as random effects, while hybrids were taken as fixed effects. This analysis made it possible to calculate the ratio of [11], in order to determine the predominance of the genes’ mode of action in the inheritance of the traits, based on the formula:

$$R=2VGCA/(2VGCA+VSCA)$$

where VGCA = variance due to general combining ability and VSCA = variance due to specific combining ability. Thus, if the ratio is close to unity (1) for a given trait, this indicates a predominance of additive gene effects. However, if it is close to zero ($0 \leq R \leq 0.5$), this reflects the dominance of non-additive gene effects [12].

Regarding genetic analysis, the same software was used to determine combining ability. This analysis allows breeding stock to be classified according to their genetic value and the best hybrid combinations to be identified. The analysis of variance was used to estimate general and specific combining abilities (GCA and SCA) using the additive model of the IV method (F1 without reciprocal or parents) [13] as follows:

$$\boldsymbol{Yijk} = \mu + \boldsymbol{gi} + \boldsymbol{gj} + \boldsymbol{sij} + \boldsymbol{rk} + \boldsymbol{eijk}$$

where Yijk = value of the cross obtained from female parent (i) and male parent (j) in the kth repetition, μ = overall population mean, gi = effect of GCA of female parent i, gj = effect of GCA of female parent j, sij = effect of SCA of cross ij, rk = effect of the kth repetition, and eijk = effect of the environment on individual ij.

3. Results

3.1. Analysis of variance of the grain yield trait and its components

The results of the analysis of variance (Table 2) showed that there was significant difference ($P< 0.001$) among genotypes as well environments for all the studied traits. Significant genotype by environment interaction effect was also observed for all variables. However, variations between hybrids were low for yield components (CV < 15%), but high for the grain yield trait (CV > 15%).

Grain yield of the hybrids varied from 1101.82 kg/ha for PI601191 x PI600954 to 9971.30 kg/ha for PI601686 x TZEI10 with an estimated mean value of 5559.88 kg/ha. The average ear diameter (ED) and ear length (EL) was respectively 42.65 mm and 15.05 cm. The number of grains per row (NGR) ranged from 20 to 47 grains, with a mean of around 35 grains and the number of rows (NR) from 11 to 20 rows with a mean value of 14 rows per ear.

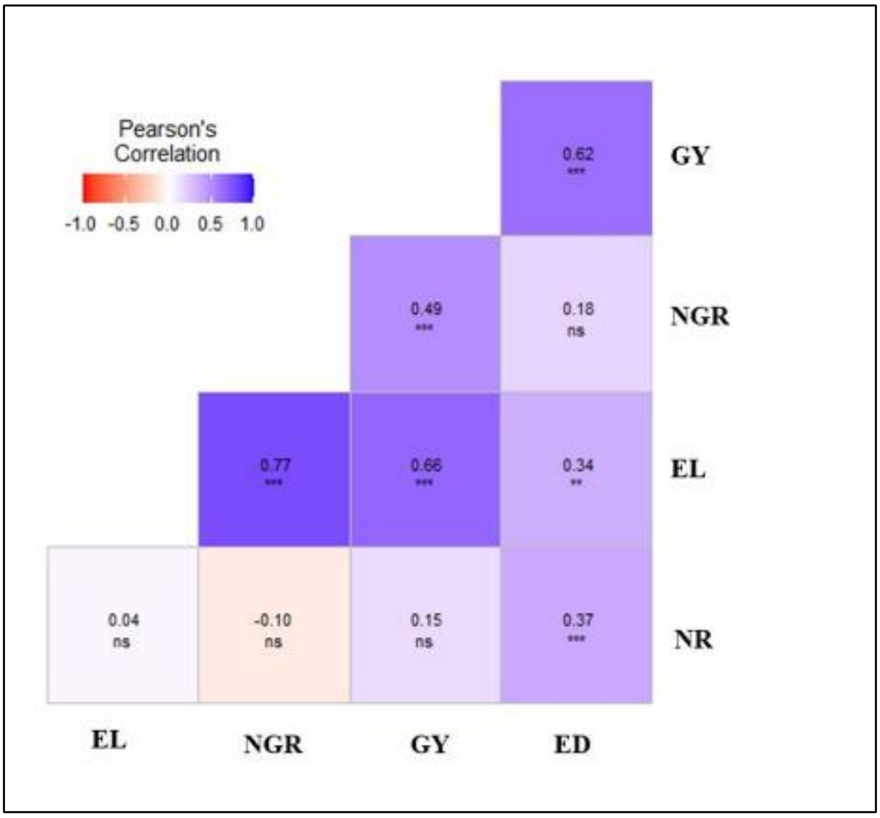
Table 2 Mean squares from analysis of variance for evaluated traits

Source	DF	GY	ED	EL	NGR	NR
Rep (Env)	12	20.31***	46.41***	88.70***	31.44***	40.30***
Env	5	180.78***	1021.73***	434.37***	182.35***	131.95***
Hybrid	77	5.02***	8.27***	6.58***	7.48***	9.52***
Env x Hybrid	385	2.00***	2.49***	2.01***	1.73***	2.18***
Minimum		1101.82	30.38	9.20	20.00	11.00
Maximum		9971.30	56.20	21.00	47.00	20.00
Mean		5559.88	42.65	15.05	35.00	14.00
CV (%)		25.56	10.57	14.78	14.23	9.52

Legend: DF = degree of freedom, GY = grain yield, ED = ear diameter, EL = ear length, NGR = number of grains per row, NR = number of rows, Env = environment, Rep = replication, CV = coefficient of variation and *, **, *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively

3.2. Relationship between the quantitative characteristics studied

The results of the correlation test between the variables studied showed strong or weak, positive or negative correlations at the 5% threshold (Figure 2). A strong positive correlation ($r = 0.62$) was observed between grain yield (GY) and ear diameter (ED). The same was observed between ear length (EL) and GY ($r = 0.66$). However, the correlation was positive but weak between the number of grains per row (NGR) and GY ($r = 0.49$). On the other hand, the correlation between GY and the number of rows (NR) per ear was weak at the 5% threshold ($r = 0.15$). As for the ear diameter (ED), it was positively and weakly correlated with the number of rows ($r = 0.37$), ear length ($r = 0.34$) and number of kernels per row ($r = 0.18$). The variables NGR and LE were strongly and positively correlated ($r = 0.77$) with each other, while the correlation between the variables LE and NR was very weak ($r = 0.04$). Finally, a weak negative correlation ($r = -0.10$) was observed between the number of grains per row (NGR) and the number of rows (NR).



Legend: GY = grain yield, ED = ear diameter, EL = ear length, NGR = number of grains per row and NR = number of rows

Figure 2 Correlation between grain yield trait and its components

3.3. Evaluation of gene action

Mean squares of the lines (GCA) and the combination (SCA) were significant (P <0.001) for grain yield and all the others measured traits (Table 3). Additionally, the means of the interaction line by environment (Env x GCA) and the interaction combination by environment (Env x SCA) were significant (P < 0.001) for all the traits. Baker ratio (R) showed dominance of GCA effects compared to SCA effects for all the observed variables.

Table 3 Results of the variance in general and specific combining abilities

Source	**DF**	**GY**	**ED**	**EL**	**NGR**	**NR**
GCA	12	20.89***	89.79***	28.06***	38.33***	116.16***
SCA	65	8.74***	8.19***	11.63***	9.43***	3.47***
Env x GCA	60	2.98***	6.96***	4.40***	3.68***	5.89***
Env x SCA	325	1.92***	1.66***	1.72***	1.62***	1.51***
$R_{GCA/SCA}$		0.83	0.96	0.83	0.89	0.99

Legend: DF = degree of freedom, GY = grain yield, ED = ear diameter, EL = ear length, NGR = number of grains per row, NR = number of rows, Env = environment, GCA = general combining ability, SCA = specific combining ability, *, **, *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively and RGCA/SCA= ratio between the variances of GCA and SCA.

3.4. Estimation of the general combining ability (GCA) effects of the lines

The results of the estimation of the combining ability of the lines are showed in Table 4. The tropical line ELN45-1-1-1 recorded positive and highly significant (P < 0.001) GCA effects for all evaluated variables. The temperate line PI601561 showed positive and highly significant (P < 0.001) GCA effects for four traits, namely GY, EL, NGR and NR. The tropical lines, FBML10 and TZEI146 showed significant (P < 0.001) and positive GCA effect for the grain yield (GY). Two temperate lines, PI600954 and PI547090 recorded significant (P <0.001) and positive GCA effects for ear diameter. Lines PI601686, PI601009, PI601575 and TZEI17 displayed significant GCA effects for ear length, lines PI601009, TZEI10, TZI18 and TZEI17 for number of grains per row and lines PI601191, PI600954, PI547090 and TZEI10 for number of rows.

Negative and significant (P < 0.001) GCA effects for grain yield were recorded by the temperate lines PI601191, PI600954 and PI601009 and the tropical lines TZI18 and TZEI17.

Table 4 General combining ability (GCA) of parental lines

Lines	GY	ED	EL	NGR	NR
PI601561	416.25***	-0.02	0.74***	0.69***	0.47***
PI601686	-82.30	0.09	0.16**	-0.05	-0.80***
PI601191	-434.85***	-0.02	-0.55***	-1.69***	0.87***
PI600954	-203.49***	1.10***	-0.68***	-1.82***	0.55***
PI601009	-238.98***	-0.61***	0.11*	1.02***	-0.62***
PI547090	73.49	1.17***	0.003	-0.83**	0.50***
PI601575	-48.84	0.01	0.12*	-1.06***	-0.11**
FBLM10	377.49***	1.59***	-0.15**	0.16	-0.60***
TZEI146	242.41***	-1.12***	-0.19***	-1.04***	-0.71***
TZEI10	-23.79	-1.12***	-0.07	1.15***	0.24***
TZI18	-236.12***	-1.47***	-0.16**	0.84***	-0.38***
TZEI17	-257.51***	-1.50***	0.22***	1.22***	-0.27***
ELN45-1-1-1	416.24***	1.89***	0.44***	1.41***	0.85***

Legend: GY = grain yield, ED = ear diameter, EL = ear length, NGR = number of grains per row, NR = number of rows and *, **, *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively

3.5. Estimation of the specific combining ability (SCA) effects of hybrids

The results of the estimation of the specific combining ability (SCA) of hybrids showed in Table 5 revealed significant or non-significant SCA effects for the studied traits. Four combinations, viz ELN45-1-1-1 x PI601686, TZEI10 x PI547090, FBML10 x PI601575 and TZEI17 x PI60157 had positive and significant SCA effects for grain yield at the threshold P < 0.05, two combinations including, FBML10 x PI601191 and PI601575 x PI547090 had positive significant SCA effects for grain yield at the threshold P < 0.01 and 12 combinations (PI601575 x PI601686, TZEI10 x PI601191, TZI18 x PI601191, TZEI17 x PI601191, FBML10 x PI600954, TZEI146 x PI600954, TZEI17 x PI600954, ELN45-1-1-1 x PI600954, FBML10 x PI601009, TZEI146 x PI601009, TZEI10 x PI601009 and TZI18 x PI547090) revealed significant positive SCA effects at the threshold P < 0.001. Thus, it appears that "tropical x temperate" combinations are more numerous (16 positive and significant combinations) than "temperate x temperate" combinations (two combinations). In addition, eight (08) combinations, all of the "tropical x temperate" type (ELN45-1-1-1 x PI601686, FBML10 x PI601575, FBML10 x PI601191, FBML10 x PI600954, TZEI146 x PI600954, ELN45-1-1-1 x PI600954, FBML10 x PI601009 and TZEI146 x PI601009) have at least one parent that exhibits a positive and significant GCA effect on grain yield (GY).

For ear length, three hybrids from "temperate x tropical" combinations (TZEI17 x PI600954, TZEI10 x PI601009 and TZEI146 x PI601191) showed positive and significant SCA effects. Four "tropical x temperate" combinations, namely "TZI18 x PI600954, TZEI17 x PI601191, FBML10 x PI600954 and TZEI146 x PI600954," showed significant positive SCA effects for the number of kernels per row. Regarding the number of rows, the results show that two hybrids, "TZI18 x PI601561 and ELN45-1-1-1 x PI601191," showed positive and significant SCA effects. However, none of the combinations showed significant positive SCA effect for the ear diameter.

Table 5 Specific combining ability (SCA) effects of hybrids

Hybrids	GY	ED	EL	NGR	NR	Hybrids	GY	ED	EL	NGR	NR
PI601686 x PI601561	204.78	-0.09	0.29	0.77	-0.23	TZI18 x PI600954	53.04	0.83	0.79	2.89**	0.16
PI601191 x PI601561	208.70	0.67	0.81	1.15	0.19	TZEI17 x PI600954	633.48***	0.31	1.03*	0.88	0.23
PI600954 x PI601561	317.11	0.82	0.44	0.30	-0.05	ELN45-1-1-1 x PI600954	945.70***	0.88	0.69	1.39	0.32
PI601009 x PI601561	-112.52	1.15	-0.63	0.17	-0.04	PI547090 x PI601009	-733.81***	-0.97	-0.64	-2.95**	-0.39
PI547090 x PI601561	-179.89	-0.60	-0.87	-2.13*	-0.56	PI601575 x PI601009	-925.85***	-1.39	-1.39**	-4.44***	-0.07
PI601575 x PI601561	204.91	0.71	-0.03	0.80	-0.19	FBML10 x PI601009	647.68***	0.85	0.00	-0.56	0.55
FBML10 x PI601561	-325.42	-2.03	-0.47	0.84	-0.61	TZEI146 x PI601009	627.09***	-0.04	0.73	1.36	0.23
TZEI146 x PI601561	101.03	0.54	0.05	0.37	0.04	TZEI10 x PI601009	742.11***	0.14	1.05*	2.06	-0.32
TZEI10 x PI601561	-12.77	-0.23	0.09	-0.42	0.32	TZI18 x PI601009	195.13	0.26	0.51	1.98	0.25
TZI18 x PI601561	-347.28	0.20	0.63	-0.73	0.75*	TZEI17 x PI601009	-454.40*	-0.05	-0.66	-0.75	0.00
TZEI17 x PI601561	99.81	-0.98	0.69	1.66	0.23	ELN45-1-1-1 x PI601009	-370.54	-0.72	-0.82	-0.39	-0.24
ELN45-1-1-1 x PI601561	-158.44	-0.17	-1.01*	-2.77**	0.14	PI601575 x PI547090	536.89**	0.48	0.25	1.62	0.11
PI601191 x PI601686	-163.96	0.26	-0.64	-1.17	-0.10	FBML10 x PI547090	18.31	0.51	0.25	0.22	0.29
PI600954 x PI601686	-432.17*	-0.25	-0.89	-2.73*	-0.30	TZEI146 x PI547090	168.21	-0.57	-0.50	-0.82	-0.38
PI601009 x PI601686	65.35	0.65	0.72	2.03	0.19	TZEI10 x PI547090	407.02*	1.75	1.30*	1.76	0.57
PI547090 x PI601686	-513.30**	-2.29*	-0.96	-1.91	0.29	TZI18 x PI547090	678.74***	0.44	0.38	0.71	0.17
PI601575 x PI601686	706.44***	0.73	0.58	1.96	0.19	TZEI17 x PI547090	347.28	0.49	0.37	1.01	-0.19
FBML10 x PI601686	122.82	0.44	0.89	-1.37	0.32	ELN45-1-1-1 x PI547090	-285.55	0.35	0.48	1.44	-0.38
TZEI146 x PI601686	-105.32	0.34	0.40	1.74	0.13	FBML10 x PI601575	395.36*	0.45	-0.29	1.02	-0.08
TZEI10 x PI601686	-228.82	-0.56	-0.43	-0.54	0.34	TZEI146 x PI601575	-221.14	0.74	-0.21	-0.66	0.07

TZI18 x PI601686	-54.38	0.34	0.04	-0.11	-0.85**	TZEI10 x PI601575	105.61	0.31	0.76	1.73	-0.14
TZEI17 x PI601686	-41.45	-0.18	-0.26	0.48	0.22	TZI18 x PI601575	174.36	-0.05	-0.12	-0.06	0.35
ELN45-1-1-1 x PI601686	440.00*	0.61	0.27	0.84	-0.18	TZEI17 x PI601575	404.12*	1.09	0.81	1.97	-0.10
PI600954 x PI601191	-2522.71***	-4.80***	-3.16***	-6.72***	0.03	ELN45-1-1-1 x PI601575	-98.05	0.45	0.33	0.26	0.26
PI601009 x PI601191	202.48	-0.28	0.14	1.72	-0.56	TZEI146 x FBML10	-1054.42***	-1.72	-0.48	-0.65	-0.39
PI547090 x PI601191	-364.23	0.14	0.20	-0.35	0.34	TZEI10 x FBML10	84.75	-0.43	0.00	-0.30	0.15
PI601575 x PI601191	-874.05***	-1.23	-0.57	-2.15*	0.10	TZI18 x FBML10	57.75	0.06	-0.26	-0.77	-0.07
FBML10 x PI601191	606.43**	1.46	0.43	0.92	-0.44	TZEI17 x FBML10	-190.89	-0.09	-0.36	-1.77	0.27
TZEI146 x PI601191	103.76	0.95	1.11*	0.94	0.21	ELN45-1-1-1 x FBML10	-1031.90***	-1.42	-0.14	-0.51	0.20
TZEI10 x PI601191	839.90***	-0.20	0.50	1.85	-0.41	TZEI10 x TZEI146	-308.39	-0.64	-0.56	-1.20	-0.30
TZI18 x PI601191	999.54***	1.34	0.65	1.38	-0.04	TZI18 x TZEI146	-57.71	-0.34	-0.11	0.03	0.35
TZEI17 x PI601191	1002.59***	1.73	0.98	2.78**	0.03	TZEI17 x TZEI146	-239.05	-0.48	-0.63	-1.83	-0.12
ELN45-1-1-1 x PI601191	-38.45	-0.04	-0.44	-0.36	0.65*	ELN45-1-1-1 x TZEI146	285.01	-0.52	-0.26	-1.50	0.32
PI601009 x PI600954	117.28	0.41	0.98	-0.23	0.39	TZI18 x TZEI10	-791.61***	-0.30	-1.06*	-2.75**	-0.02
PI547090 x PI600954	-79.68	0.26	-0.25	1.42	0.12	TZEI17 x TZEI10	-721.34***	-0.04	-1.20*	-2.11*	0.19
PI601575 x PI600954	-408.61*	-2.29*	-0.12	-2.06	-0.48	ELN45-1-1-1 x TZEI10	-122.56	0.03	-0.06	0.24	-0.31
FBML10 x PI600954	669.52***	1.92	0.42	2.94**	-0.18	TZEI17 x TZI18	-1091.26***	-2.56	-1.59**	-3.11**	-0.52
TZEI146 x PI600954	700.93***	1.75	0.47	2.24*	-0.16	ELN45-1-1-1 x TZI18	183.67	-0.21	0.13	0.54	-0.53
TZEI10 x PI600954	6.11	0.16	-0.39	-0.32	-0.08	ELN45-1-1-1 x TZEI17	251.12	0.76	0.83	0.80	-0.25

Legend: GY = grain yield, ED = ear diameter, EL = ear length, NGR = number of grains per row, NR = number of rows, and *, **, *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively

4. Discussion

The results of the analysis revealed significant variability among the hybrids. The mean squares were significant for all traits within the hybrids, indicating the existence of genetic variability among them. This variability provides a wide range of choices for improving these traits. In addition, the results showed significant difference between environments, indicating the uniqueness of each environment and the variation of the traits performance based on an environment. Also, the presence of significant ''Env x Hybrid'' interaction mean squares for most variables is an indication of the impact of the interaction in the performance of the hybrids traits. In fact, the performance of each hybrid depends on the environment conditions that prevail and selection of hybrid should be targeted for a specific environment. This significant interaction for all traits would make it possible to identify and select the most efficient and stable hybrids across environments. Indeed, it was highlighted by [14] that the significance of the interaction between the two factors (Env x Hybrid) makes it possible to identify and select the best genotypes. Furthermore, according to the studies by [15], the significant ''Env x Hybrid'' interaction recorded shows the importance of multi-environmental evaluations of hybrids in order to offer them to users.

The existence of strong positive correlations between grain yield (GY) and ear diameter (ED), ear length (EL), and number of grains per row (NGR) indicates the contribution of theses variables to grain yield. In other words, improving one of these traits would have a positive impact on yield. For future studies, it will be possible to focus on improving these traits within a given variety in order to increase yield. Selecting parental lines with the best GCA effects for these traits would improve the yield of hybrids for future generations. Ouedraogo [16] reported that traits such as number of pods per plant, number of grains per pod, and 100-grain weight are positively correlated with yield per plant in voandzou. Based on this, they suggested that accessions with high values for these traits, such as number of pods per plant, pod weight, and seed weight, could produce higher yields.

Combining ability is an essential aspect of any plant breeding program. The significant difference among GCA and SCA for grain yield and its components shows the presence of both additive and non-additive genes in the inheritance of the traits and the variability of the genes content of the genetic material. Previous studies have shown the action of additive and non-additive genes on yield and other traits of interest in maize [17]. In addition, [18] reported that both general and specific combining ability are important for grain yield in maize. According to [19], the variation in additive variance suggests great potential for classifying parental lines into heterotic groups while identifying representative lines. However, the significant SCA effects reveal that the backcrossing method could be used to create three-way or double hybrids and develop synthetic varieties. The interactions between "Env x GCA and Env x SCA'' were significant for all measured traits. These results are interesting because they will enable the selection of lines or hybrids based on their ability to adapt to each environment. Badu-Apraku [19] found a significant "Env x SCA" interaction for grain yield and most of the traits measured. They also reported that this indicates differential performance of hybrids under contrasting environmental conditions, thus highlighting the need to select the hybrids suited to each environment

The baker ratio was close to unity for all traits. This would indicate a dominance of additive gene action over non-additive action in controlling traits. Lin [20] also reported the dominance of additive gene effect over mon-additive gene action on maize. Similarly, authors such as [21], [22] and [23] found that additive gene action was more important than non-additive gene action for maize grain yield. Furthermore, these results indicate that an improvement in these traits can be achieved through recurrent selection [15].

General combining ability (GCA) is an essential criterion in genetic improvement of maize. It allows the selection of the best lines for a desired trait. The lines with desirable GCA effects for grain yield and yield component selected in this study could be good combiners for yield improvement and are likely to transfer the desirable characteristics to their offspring in hybrid combination. In addition, these lines can be used as parents for further improvement program (recurrent selection, pedigree selection) and developing heterotic groups as well as synthetic and hybrid varieties with high yield potential. Akinwale [24] endorsed the same idea in their study that lines with significant and positive GCA effects can be used to develop heterotic populations. Furthermore, they can be used as testers for temperate and tropical material in the creation of new varieties. ELN45-1-1-1 and PI601561 particularly carried out desirable GCA effects for majority of measured traits, with the exception of the ear diameter (ED) for line PI601561 and could be potential parent for hybrid development, new inbred lines generations and best tester for classifying inbred lines into heterotic group. This shows that these two lines could have favorable alleles for these different variables. Badu-Apraku [19] stipulate that lines with the best GCA effects have alleles that are beneficial for grain yield and could have a positive effect on the grain yield of their offspring under environmental conditions.

With regard to specific combining ability (SCA), significant values were recorded for the traits studied. For grain yield, 14 combinations showed positive and significant SCA effects with at least one parent showing a good GCA effect for grain yield. Bordes [24] states that lines with good GCA or SCA effects can be used to create two-way or three-way hybrids. Thus, hybrids with good SCA can be used in the development of three-way hybrids while crossing them with a line with good GCA for this trait. Among them, two hybrids TZEI146 x PI547090 and ELN45-1-1-1 x TZEI146 both have parents with good GCA and the different parents of these hybrids come from two different heterotic groups. This shows that these two simple hybrids can be used to create double hybrids. [25] showed that a double hybrid is obtained by crossing two simple hybrids belonging to two complementary groups and exhibiting good SCA effects for the given trait. Furthermore, [26] emphasized that identifying a parent with a good combination and a hybrid with good SCA for a given trait in a breeding program is essentially based on the values and signs of combining ability effects, as they allow for better selection.

5. Conclusion

This study showed that the population evaluated exhibits considerable variability. It also revealed the significant influence of genotypes, environments, and their interaction for all of the traits. Furthermore, it appears that trait inheritance is linked to both additive and non-additive genes for all of the variables. However, additive variance dominated for all traits. Furthermore, lines with positive and significant GCA effects for the grain yield were identified in the current study. These include the temperate line PI601561 and three tropical lines ELN45-1-1-1, FBML10 and TZEI146. These lines can be used as representative parents for the classification of the program's genetic material into heterotic groups, but they can also serve as testers for the creation of new high-yielding hybrids. The results also showed that some hybrids had positive and significant SCA effects for the grain yield. These hybrids will be used to create three-way and double hybrids for future studies. These results are will be serve as a guide the improvement of breeding programs in the country.

Compliance with ethical standards

Acknowledgments

This study was carried with the support of the ''Projet d'Appui à l'Enseignement Superieur (PAES)''. The authors would like to express our gratitude to Institute for the Environment and Agricultural Research (INERA) in Farako-Bâ, in particular the Maize, Wheat and Emerging Plants Section of the Traditional Cereals Program, for the genetic material and the study sites.

Disclosure of conflict of interest

The authors declare that they do not have any conflict of interest

Contributions of authors

ST: followed the field trial, collected the data and participated in the analysis and writing of the manuscript. AD: designed and planned the study, supervised the work, and oversaw the data analysis and manuscript review. MS & JS reviewed the manuscript. STC: followed the trials and contributed in data collection.

References

[1] Souratié W, Koinda F, Decaluwé B, Samandoulougouc R. *Agricultural policies, employment, and women's income in Burkina Faso*. 2018; pp101-125

[2] Semassa AJ, Padonou SW, Anihouvi VB, Akissoe NH, Aly D, Adjanohoun A, Baba-Moussa L. Varietal diversity, quality, and use of maize (*Zea mays* L.) in West Africa: Critical Review, ed. *European Scientific Journal*. 2016; 12 (18): 21 pp.

[3] Bono M. Maize variety improvement in Upper Volta: review of 1972-1980. Tropical *Agronomy*. 1981; 36(4), 347-355

[4] DGESS/MARAH. *Permanent Agricultural Survey Final results of the 2023-2024 agricultural season*, Burkina Faso, 2024. 50 pp.

[5] Reif JC, Melchinger AE, Xia XC, Warburton ML, Hoisington DA, Vasal SK, Srinivasan G, Bohn M, Frisch M. Genetic distance based on simple sequence repeats and heterosis in tropical maize populations. *Crop Sci*. 2003; 43(4): 1275-1282.

[6] Brown J, Caligari PDS, Campos HA. Plant Breeding. 2nd ed. of Introduction to Plant Breeding – revised and updated. *John Wiley & Sons*, 2014.

[7] Hannachi A, Fellahi Z, Bouzerzour H, Boutekrabt A. Diallel-cross analysis of grain yield and stress tolerance-related traits under semi-arid conditions in Durum wheat (Triticum durum Desf.). *Electronic Journal of Plant Breeding*. 2013; 4(1): 1027-1033.

[8] Nigussie M, Zelleke H. Heterosis and combining ability in a diallel among eight elite maize populations. *Afr. Crop Sci. J*. 2001; 9, 471-479.

[9] Météo INERA. Relevé des quantités d'eau tombées et des températures au cours des campagnes 2021/2022 et 2022-2023. *Stations météoroliques de la vallée du Kou et de Houndé*.

[10] Guinko S. *Contribution to the study of vegetation and flora in Upper Volta*. Doctoral thesis in Natural Sciences. University of Bordeaux III. 1984; 318 p.

[11] Baker RJ. Diallel analysis programs. *Crop Sci*. 1978; 18, 535-536.

[12] Fasahat P, Rajabi A, Rad JM, Derera J. Principles and utilization of combining ability in plant breeding. *Biometrics & Biostatistics International Journal. 2016;* 4: 1-24

[13] Griffing B. Concept of general and specific combining ability in relation to diallel crossing system. *Australian Journal of Biological Sciences*. 1956; 9: 463-493.

[14] Badu-Apraku B, Abamu FJ, Menkir A, Fakorede MAB, Obeng-Antwi K. Genotype by environment interactions in the regional early variety trials in West and Central Africa. *Maydica*. 2003; 48, 93-104

[15] Badu-Apraku B, Annor B, Oyekunle M, Akinwale RO, Fakorede MAB, Talabi AO, Akaogu IC, Melaku G, Fasanmade Y. Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments. *Field Crop. Res*. 2015; 183, 169-183

[16] Ouedraogo M, Ouedraogo TJ, Tignere JB, Balma D, Dabiré BC, Konaté G. Characterization and evaluation of accessions of Bambara groundnut. *Sci. Nat*., 2008. 5(2), pp. 191–197

[17] Sujiprihati SS, Saleh GB, Ali ES. Combining ability analysis of yield and related characters in single cross hybrids of tropical maize (*Zea mays* L.). *SABRAO Journal of Breeding and Genetics*. 2001; 33(2) 111-120

[18] Aguiar AM, Carlini-Garcia LA, Silva ARD, Santos MF, Garcia AAF, Souza JRCLD. Combining ability of inbred lines of maize and stability of their respective single crosses. *Scientia Agricola*. 2003; 60: 83-89.

[19] Badu-Apraku B, Obisesan O, Olumide OB, Toyinbo J. Gene Action, Heterotic Patterns, and Inter-Trait Relationships of Early Maturing Pro-Vitamin a Maize Inbred Lines and Performance of Testcrosses under Contrasting Environments. *Agronomy*. 2021; 11, 1371.

[20] Lin SF, Chen C. Studies on the combinability of maize's main agronomic traits (*Zea mays* L.). *J. Agric. Assoc*. Chine. 1986; 136: 6-14

[21] Vacaro E, Barbosa Neto JF, Pegoraro DG, Nuss CN, Conceição, LDH. Combining ability of twelve maize populations. *Pesquisa Agropecuária Brasileira*, 2002. 37(1), 67-72

[22] El-Shouny K, El-Bagoury OH, El-Sherbieny H, AlAhmad S. Combining ability estimates for yield and its components in yellow maize (*Zea mays* L.) under two plant densities. *Egypt. J. Plant Breed*, 2003. 7(1), 399-417

[23] Ojo GOS, Adedzwa DK, Bello LL. Combining Ability Estimates and Heterosis for Grain Yield and Yield Components in Maize (*Zea mays* L.). *J. of Sustainable Development in Agriculture & Environment*. 2007; Vol. 3:49-57

[24] Akinwale RO, Badu-Apraku B, Fakorede MAB, Vroh-Bi I. Heterotic grouping of tropical early-maturing maize inbred lines based on combining ability in Striga-infested and Striga-free environments and the use of SSR markers for genotyping. *Field Crop. Res*. 2014; 156, 48-62

[25] Bordes J. Création de lignées haploïdes doublées de maïs par gynogenèse induite in situ: amélioration de la méthode et intégration dans les schémas de sélection. *Biologie végétale*. Université Blaise Pascal - Clermont-Ferrand II, 2006. Français. 133 pp

[26] Hannachi A, Fellahi Z, Rabti A, Guendouz A, Bouzerzour H. 2017. Combining ability and gene action estimates for some yield attributes in durum wheat (*Triticum turgidium* L. var. durum). *J. Fundam. Appl. Sci*. 2017; 9(3), 1519-1534