Combining ability performance and heterotic grouping of maize (Zea mays) inbred lines in testcross formation in Western Amhara, North West Ethiopia

Melkamu Elmyhun1*, Chale Liyew1, Abyneh Shita1 and Mekuanint Andualem1

Abstract: Development and selections of appropriate parents’ are perquisites for hybrid variety development and need knowledge of heterotic grouping and combining ability. The research was investigated to identify good general combiner inbred lines and good specific combiner three-way crosses using randomized complete block design with three replications. Sixteen crosses (eight inbred lines crossed with two testers) and three standard checks were evaluated for yield and yield components. Analysis of variance disclosed significant differences among genotypes for most traits indicating existence of variability among genotypes. General combining ability (GCA) for grain yield demonstrated five inbred lines and T2 was good general combiner for grain yield. Specific combining ability (SCA) analysis revealed eight hybrids were good specific combiner for grain yield. Three hybrids

ABOUT THE AUTHORS

Melkamu Elmyhun is a breeder at Adet Agricultural Research Center, Amhara regional Agricultural Research Institute in Ethiopia. Melkamu has handled different research projects in field crops focusing on maize and contributed a lot for improvement of maize productivity in the region and in the country. He has participated actively in national research centers, NGOs and international research centers and has good collaboration. He has dedicated in resource management and doing research alone or in teamwork. Melkamu is highly devoted in creating genotypic variability which is the base for the development of better-yielding varieties.

Chale Liyew and Abayneh Shita are researchers at Adet Agricultural Research Center, Amhara regional Agricultural Research Institute in Ethiopia. They have great skills in resource, data and trial management with great interest and participation in maize crossing.

Mekuanint Andualem is a plant protection researcher at Adet Agricultural Research Center, Amhara regional Agricultural Research Institute in Ethiopia. Mekuanint has been involved in maize-breeding in early generation evaluation for disease resistance or tolerance.

PUBLIC STATEMENT OF INTEREST

Maize is the most important cereal crop produced on 2.1 million hectare and used for varietal food types in Ethiopia. Maize faced different challenges like shortage of biotic and abiotic stress resistant and high-yielding varieties that caused low maize productivity. Development inbred lines, crossing with testers and among them using different mating designs and evaluation of their hybrids is crucial work to produce stress resistant high-yielding hybrids. Adet maize breeding team generated lines which are better in abiotic and biotic stress tolerant. These lines have to be used for development of crosses that will be evaluated and helped to identify lines with desirable general combining ability and crosses with better performance in yield and specific combining ability (SCA). Eight lines were crossed with two testers and 16 crosses were produced and evaluated at Adet. Five lines were good general combiners for grain yield and as well as eight crosses with good SCA were selected. Lines were grouped in to two heterotic groups.
explained good correspondence between mean grain yield and SCA. Four inbred lines (L1, L2, L5 and L7) were grouped in to heterotic group A and the remaining four lines were classified in to heterotic group B. Inbred lines from different heterotic group can be used for hybrids development and lines within a heterotic group and good GCA can be used for synthetic varieties development. Crosses with desirable SCA and better yield performance will be tested in multi-location trials.

**Subjects:** Agriculture & Environmental Sciences; Agriculture; Crop Science

**Keywords:** general combining ability; specific combining ability; hybrid; tester

1. Introduction

Maize (Zea mays L.) is one of the most important cereal crops in the world following wheat and rice. It is widely used for food, feed, fuel and fiber in many parts of the world. Maize has broad morphological variability and geographical adaptability due to its cross-pollinated nature. According to World Food and Agriculture [FAO] (2019), 197 million hectares of land was covered by maize and produced 1,134 million tons of maize grain in 2017 production season.

Maize is one of the major cereals that play the core role of Ethiopia’s agriculture and food economy. It has largest small holder farmers’ coverage and greatest production and consumption compared to other cereals (Central Statistical Agency [CSA], 2018). According to Central statistical Agency 2017/18, maize exceeds teff, sorghum and wheat by 58.9, 62.4 and 80.7%, respectively, with total production of 8.4 million tons produced over 2.1 million hectares. About 11 million farmers contributed for maize production and productivity (3.9 ton ha\(^{-1}\)). Amhara region shares 24.7% in total production cultivated over 0.52 million hectares of land with productivity of 3.98 ton ha\(^{-1}\). Current maize total production and productivity is achieved through the effort made by research since 1952. Since 1970, many pest and disease resistance open pollinated and hybrid varieties that contributed a lot for maize total production and productivity, were developed and released for different agroecologies in Ethiopia by Ethiopian Institute of Agricultural Research (EIAR) in collaboration regional research centers. But the total yield produced and productivity increments are far below the attainable potential of maize and relative to developed worlds. The productivity of maize in USA in 2017 was 11.88 ton ha\(^{-1}\) (United States Department of Agriculture [USDA], 2018), which is far above the national maize productivity in Ethiopia. The poor adoption of improved technologies mainly by small-scale farmers, shortage of high-yielding varieties, biotic and abiotic stresses (Mosisa et al., 2012; Worku et al., 2002) are the chief contributors for low yield. This problem can be addressed partly by developing high-yielding and stressed resistance varieties which require the identification of potential parents with their superior hybrid.

Hybrids play crucial role in maize production increment (Aslam, Sohail, Maqbool, Ahmad, & Shahzad, 2017; Karim, Ahmed, Akhi, Talukder, & Mujahidi, 2018) and food security. Hybrid maize varieties development needs selection of appropriate parents (inbred lines) which is the covert of success in hybrid maize development. Identification of high-yielding hybrids needs development and careful selection of parents based on their combining ability and genetic structure (Ceyhan, 2003; Hallauer & Miranda, 1988; Karim et al., 2018).

Newly developed inbred lines need to be crossed with testers (inbred lines, single crosses and open-pollinated varieties) and their performance can be estimated by evaluation of their hybrids. The performance lines in hybrid combination and their crosses are assessed through estimation of combining ability. Combining ability is the ability of an inbred to transmit desirable performance to its hybrid progenies. Combining ability analysis is an important genetic tool used to the estimates of general combining ability (GCA) of parents and specific combining ability (SCA) of crosses and facilitated selection of the desired parents and crosses (Ahmed et al., 2017; Aliu, Fetahu, & Salillari, 2008). Griffing (1956) stated that GCA is the average performance of a parent in a series of hybrid
combinations, whereas SCA is the difference in performance of certain hybrid combinations in relation to what would be expected, based on the GCA. GCA is regarded as additive gene effects while SCA reflects the non-additive gene actions (Sprague & Tatum, 1942). A number of new inbred lines need to be developed and evaluated for hybrid combination. Information and knowledge on combining ability extremely important for hybrid and open-pollinated variety development. This study was investigated to identify appropriate inbred lines with good general combiners and three-way crosses with good specific combiners.

2. Materials and methods

2.1. Genetic materials

Sixteen three-way crosses and three standard checks (BH-661, BH-540 and AMH-851) (Table 1) were tested in randomized complete block design with three replications at Adet research center/research station in 2018 in main cropping season. Eight new inbred lines were crossed with two single cross-testers (CML-395 XCML-202(T1) and CML-442 XCML-312(T2)) using Line by Tester mating design to generate 16 three-way crosses in 2016/17 irrigation seasons at Koga irrigation site. Testers utilized for crossing were initially developed by CIMMYT and have been widely used to study combining ability and heterotic grouping of newly developed inbred lines by national maize breeding programs in east and central Africa regions. Crossing was done by two staggered sowings of testers at an interval of seven days to capture different flowering dates of new lines. Ears of testers were bagged before the emergence of silk to control unnecessary cross-pollination. Tassel

| Pedigree | Code | Origin | Tester-1  | Code | Tester-2  |
|----------|------|--------|-----------|------|-----------|
|          |      |        | (CML395/  |      | (CML442/  |
|          |      |        | CML202)  |      | CML312)   |
|          |      |        | // Lines  |      | // Lines  |
| BKLO02   | L1   | Adet   | CML395/   | H1   | CML442/   |
|          |      |        | CML202//  |      | CML312//  |
|          |      |        | BKLO02    |      | BKLO02    |
| OPV6521  | L2   | Adet   | CML395/   | H3   | CML442/   |
|          |      |        | CML202//  |      | CML312//  |
|          |      |        | OPV6521   |      | OPV6521   |
| 16211    | L3   | Adet   | CML395/   | H5   | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | 16211     |      | 16211     |
| OPV4122  | L4   | Adet   | CML395/   | H7   | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | OPV4122   |      | OPV4122   |
| OPV5311  | L5   | Adet   | CML395/   | H9   | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | OPV5311   |      | OPV5311   |
| 14322    | L6   | Adet   | CML395/   | H11  | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | 14322     |      | 14322     |
| 13116    | L7   | Adet   | CML395/   | H13  | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | 13116     |      | 13116     |
| OPV7411  | L8   | Adet   | CML 395/  | H15  | CML442/   |
|          |      |        | CML202//  |      | CML312/   |
|          |      |        | OPV7411   |      | OPV7411   |

| Checks   |      |        |          |      |          |
| BH-660   | H17  | Bako   |          |      |          |
| BH-540   | H18  | Bako   |          |      |          |
| AMH-851  | H19  | Ambo   |          |      |          |
bagging was done with bag made of heavy craft paper with waterproof glue to collect pure pollen from the desired male lines. Pollination was performed by dusting pollen collected in the pollen bag on the silk of the specific ear.

2.2. Trail management
Each three-way cross was planted in one row with row length of 5.25 m and spacing of 75 cm between rows and 25 cm between plants to ensure 53,333 plant populations per hectare. The recommended fertilizer rates of urea and Nitrogen-Phosphate fertilizer with Sulphur(NPS) were applied in the ratio of 200 and 200 kg ha\(^{-1}\). The whole P and one-third dose of urea were applied as basal at planting, while remaining two-third dose of urea at knee height. The remaining agronomic practices were performed based on their recommendation.

2.3. Data collection and analysis
Data were recorded on five randomly selected plants for plant height and ear height through a plot based for days to 50% tasseling, days to 50% silking, days to maturity, ear aspect, plant aspect, grain yield and disease scores (gray leaf spot, turcicum leaf blight and common rust). All cultural practices for maize production were applied as recommended at the proper time. All of data taken were subjected for analysis of variance using SAS 9.2 software. The mean squares from line x tester mating design and the GCA and specific combining ability (SCA) effects were calculated according to the procedures developed by Kempthorne (1957) and adopted by Singh and Choudhry (1979). The significance of GCA and SCA effects were tested using t test. Heterotic grouping was determined according to the CIMMYT heterotic classification system as A, B and AB. Depending on the direction of the SCA estimates such that lines displaying positive SCA with tester A were grouped towards the opposite heterotic group, and vice versa, whereas lines exhibiting positive SCA to both testers were grouped under AB heterotic group (Vasal, 1992).

3. Result and discussion
3.1. Analysis of variance and mean performance
Effective variety development is based on variation existing in a crop species which is a prerequisite to start any crop improvement. Development of hybrid maize varieties needs selection of appropriate parents (inbred lines) which is secret of achievement in hybrid maize variety development (Hallauer & Miranda, 1988). Phenotypic performance of parents may not be a good selection means as phenotypically superior lines may provide poor hybrid combinations. It is mandatory to select parents on the basis of their combining ability. Combining ability analysis is a useful genetic means to estimate GCA of parents and SCA of crosses to select the desired parents and crosses (Ahmed, Ahmed et al., 2017; Griffing, 1956; Sprague & Tatum, 1942).

Analysis of variance disclosed significant differences among genotypes for most studied traits indicating the existence of a high degree of variability among genotypes (Table 2). Significant differences among lines and interactions of parents and crosses for grain yield, days to 50% tasseling, days to 50% silking maturity date, plant height, ear height, plant aspect and ear aspect indicating wide range of variability present among them and providing the chance for selection for improvement of yield and yield-related traits. Similar results have been reported by many authors (Ahmed, Ahmed et al., 2017 and Kumar et al., 2017).

Mean performance of crosses revealed that three-way cross H3 produced the highest grain yield (10,481 kg ha\(^{-1}\)) followed by two three-way crosses H1 (9663 kg ha\(^{-1}\)) and H8 (9550 kg ha\(^{-1}\)) with over all mean value of 8502 kg ha\(^{-1}\)(Table 3). These three way crosses had better performance in grain yield compared to standard cheek AMH-851(Jibate). But no cross was found to have better performance in grain yield over standard check BH-660 and BH-540. Abebe, Wolde, and Gebreselassie (2018) investigated combining ability and heterosis of maize inbred lines and stated that none of the crosses performed better than the best standard check in grain yield.
Table 2. Analysis of variance of yield and yield-related parameters in maize (Zea mays L.)

| Source of variation | d.f. | GY     | DST   | DSS   | DM    | PH    | EH    | PAS   | EAS   | GLS   | CLR   | TLB   |
|---------------------|------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Replication         | 2    | 95790065 | 1.59  | 2.59  | 42.59 | 334.11| 730.58| 0.08  | 0.08  | 0.06  | 0.03  | 0.04  |
| Genotype (G)        | 18   | 2682237.3*| 11.21***| 11.27***| 15.04***| 994.24*| 928.12***| 0.27* | 0.82***| 0.06  | 0.04  | 0.05* |
| Cross (C)           | 15   | 2687334.2*| 12.09***| 12.31***| 14.88***| 740.76*| 388.27***| 0.31***| 0.84***| 0.06  | 0.04  | 0.05* |
| Line                | 7    | 1996166.4*| 12.26***| 9.80***| 25.62***| 1328.38*| 470.21***| 0.19  | 1.21***| 0.09  | 0.06  | 0.05* |
| Tester              | 1    | 188990.5  | 0.02  | 0.33  | 22.62* | 21.33 | 682.52***| 0.75***| 0.13  | 0.05  | 0.08  | 0.01  |
| Line x Tester       | 7    | 3335408.2*| 13.64***| 16.52***| 3.02  | 255.9  | 264.28* | 0.36***| 0.57***| 0.03  | 0.02  | 0.06* |
| Polled Error G      | 36   | 11895104  | 2.41  | 2.39  | 3.74  | 155.88 | 88.41  | 0.11  | 0.14  | 0.05  | 0.03  | 0.02  |
| Polled Error C      | 30   | 682155    | 2.63  | 2.2   | 3.7   | 112.85 | 87.2   | 0.09  | 0.13  | 0.05  | 0.03  | 0.02  |

where GY = Grain yield, DST = Days to 50% tasseling, DSS = Days to 50% silking, DM = Days to maturity, PH = Plant height, EH = Ear height, PAS = Plant Aspect, EAS = Ear aspect, GLS = gray leaf spot, CLR = common leaf rust, TLB = Turcicum leaf blight, NC = number of cob.
| ENTRY  | PEDIGREE                  | PH  | EH   | DST  | DSS  | MD   | PAS  | EAS  | GLS  | CR   | TLB  | GY(Kg/ha) | CN  |
|--------|---------------------------|-----|------|------|------|------|------|------|------|------|------|-----------|-----|
| 1      | CML395/CML202//BKL002     | 244 | 142  | 93   | 95   | 167  | 2.0  | 2.5  | 1.3  | 1.3  | 1.3  | 9663      | 52487|
| 2      | CML 442/CML312//BKL002    | 256 | 148  | 91   | 95   | 164  | 1.0  | 2.6  | 1.0  | 1.0  | 1.0  | 7700      | 57566|
| 3      | CML395/CML202//OPV6521    | 269 | 155  | 91   | 94   | 167  | 1.0  | 2.0  | 1.1  | 1.1  | 1.0  | 10481     | 66878|
| 4      | CML 442/CML312//OPV6521   | 257 | 133  | 89   | 93   | 166  | 1.0  | 2.6  | 1.0  | 1.0  | 1.0  | 8760      | 55873|
| 5      | CML395/CML202//16211      | 267 | 154  | 89   | 93   | 168  | 1.5  | 2.5  | 1.0  | 1.0  | 1.0  | 7075      | 59259|
| 6      | CML442/CML312//16211      | 257 | 144  | 90   | 94   | 165  | 1.0  | 3.1  | 1.0  | 1.0  | 1.0  | 8826      | 60106|
| 7      | CML395/CML202//OPV4122    | 287 | 164  | 90   | 93   | 168  | 1.1  | 2.0  | 1.1  | 1.0  | 1.0  | 8603      | 68571|
| 8      | CML 442/CML312//OPV4122   | 298 | 175  | 96   | 99   | 169  | 1.8  | 1.8  | 1.3  | 1.0  | 1.1  | 9550      | 56720|
| 9      | CML395/CML202//OPV5311    | 275 | 146  | 92   | 94   | 171  | 1.3  | 1.8  | 1.0  | 1.0  | 1.0  | 8708      | 66032|
| 10     | CML 442/CML312//OPV5311   | 281 | 147  | 93   | 95   | 169  | 1.3  | 2.5  | 1.0  | 1.0  | 1.0  | 8800      | 57566|
| 11     | CML395/CML202//14322      | 273 | 156  | 90   | 93   | 169  | 1.3  | 3.0  | 1.0  | 1.0  | 1.3  | 7844      | 60952|
| 12     | CML442/CML312//14322      | 286 | 153  | 91   | 94   | 167  | 1.0  | 3.0  | 1.0  | 1.0  | 1.1  | 8428      | 54180|
| 13     | CML395/CML202//13116      | 285 | 170  | 93   | 96   | 167  | 1.6  | 3.0  | 1.1  | 1.0  | 1.1  | 9187      | 72804|
| 14     | CML442/CML312//13116      | 274 | 149  | 91   | 94   | 164  | 1.3  | 3.0  | 1.0  | 1.0  | 1.1  | 8177      | 55876|
| 15     | CML 395/CML202//OPV7411   | 263 | 157  | 92   | 95   | 163  | 1.5  | 2.3  | 1.3  | 1.3  | 1.0  | 6815      | 71958|
| 16     | CML 442/CML312//OPV7411   | 243 | 136  | 87   | 89   | 164  | 1.0  | 2.5  | 1.3  | 1.1  | 1.3  | 9141      | 77037|
| 17     | BH-660                    | 308 | 210  | 90   | 94   | 171  | 1.3  | 1.5  | 1.0  | 1.0  | 1.0  | 9085      | 57566|
| 18     | AMH-851                   | 244 | 1336 | 89   | 92   | 166  | 1.5  | 2.1  | 1.1  | 1.0  | 1.0  | 6555      | 56720|

(Continued)
| ENTRY | PEDIGREE | PH  | EH  | DST | DSS | MD  | PAS | EAS | GLS | CR  | TLB | GY(Kg/ha) | CN   |
|-------|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------|------|
| 19    | BH-540   | 283.0 | 166.7 | 90.7 | 93.3 | 167.0 | 1.50 | 2.50 | 1.17 | 1.17 | 1.00 | 8147 | 61799  |
| MEAN  |          | 271.3 | 155.3 | 91.3 | 94.2 | 167.3 | 1.33 | 2.39 | 1.11 | 1.06 | 1.10 | 8502 | 61576  |
| LSD   |          | 17.9  | 15.6  | 2.57 | 2.56 | 3.22 | 0.56 | 0.58 | -   | -   | 0.33 | 2741 | 13251  |
| CV (%)|          | 3.79  | 6.1  | 1.7  | 1.6  | 1.2  | 25.50 | 14.80 | 20.55 | 17.70 | 18.34 | 19 | 12.99   |
| R     |          | 0.82  | 0.85  | 0.70  | 0.70  | 0.72  | 0.55  | 0.78  | 0.53  | 0.56  | 0.54  | 0.53 | 0.56   |
| SIGNIFICANT | ** | *** | *** | *** | *** | * | *** | NS | NS | * | * | * | * |
Maturity date of crosses indicated cross H15 was earlier in maturity compared to standard checks and cross H14 had short maturity date than standard check BH-660 and BH-540.

3.2. Analysis of combining ability

Developing high-yielding hybrids depend on careful choice of parents. Information regarding general and SCA is very important to select desirable parents and crosses. Four characters (plant height, ear height, grain yield and number of cobs per hectare) exhibited significant general combining abilities (Table 4). Inbred lines L1, L2, L3 and L8 contributed negative GCA effects for plant and ear height indicated that these lines can be utilized for developing short and earlier hybrids to minimize yield loss due to root and stem lodging. L5 had significant positive GCA for plant height but negative significant GCA for ear height.

Ahmed, Ahmed et al. (2017), Kuselan et al. (2017) and Matin et al. (2016) found inbred lines that showed negative plant and ear height GCA effects. L4 and L6 recorded positive significant GCA effects for plant height and were good general combiners for tallness.

GCA for grain yield showed five inbred lines (L1, L2, L4, L5, L7) and T2 had significant positive effects. These lines were good general for grain yield and can be used for development of high-yielding hybrids and synthetic varieties by contributing desirable alleles. Positive significant GCA effects for maize lines indicated that they are desirable parent for maize hybrid development and involvement in the maize breeding program as they can be good allele source in the process of varietal development (Rawi, 2016). Inbred lines L3, L6 and L8 possessed significant positive GCA effects for grain yield signifying that those lines were undesirable combiner for developing high-yielding hybrids and synthetic varieties. Shah, Rahman, Ali, Bazai, and Tahir (2015) and Andayani et al. (2018) identified inbred lines with positive significant and lines with significant negative GCA effects for grain yield in their studies.

SCA effects are connected with dominance and epistatic component of variations. Significant SCA showed comparative importance of interactions in determining the performance of produced hybrids. SCA effect analysis revealed that eight three-way crosses had significant positive SCA effects for grain yield (Table 5). The remaining eight crosses expressed significant negative SCA effects for the same trait. This finding is in line with the result reported by Ahmed, Ahmed et al. (2017), Abebe et al. (2018), Chemada, Alamerew, Tadesse, and Menamo (2015) and Natol (2017) who reported both positive and negative significant SCA for grain yield. Positive SCA effects resulted from crossing of lines from different heterotic group but negative SCA effects due to crossing of lines from the same heterotic group.

Positive significant SCA effects indicated that produced hybrids were good specific combiners for developing high-yielding hybrids. Hybrids H1, H3 and H8 provided high mean grain yield and possessed desirable significant high SCA effects, revealing good correspondence between mean grain yield and SCA effects. But remaining hybrids had positive significant high SCA effects which were not consistent with high mean grain yield performance. Abebe et al. (2018) and Gichuru, Njorog, Ininda, and Peter (2011) reported similar results. Inbred lines heterotic groups could be identified based on the value of SCA effects for grain yield. Three heterotic groups were identified depending on the direction of the SCA estimates. Lines displaying positive SCA effects with a tester were grouped toward the opposite heterotic group, whereas lines exhibiting positive SCA effects to both testers were grouped toward both groups, and lines that expressed negative SCA effects with the two testers could be discarded (Vasal et al., 1992 and Parentoni et al., 2001).

Kanyamasoro, Karungi, Asea, and Gibson (2012) explained that positive SCA effects indicates that inbred lines are in different heterotic group, whereas negative SCA effects indicates genetic similarity of the parents.
| LINE | PH    | EH     | DST | DSS  | MD   | PAS  | EAS  | GY    | CN    |
|------|-------|--------|-----|------|------|------|------|-------|-------|
| L1   | −19.8**| −6.2** | 0.81| 0.96 | −1.10| 0.19 | −0.53| 71.6***| −7089.7***|
| L2   | −6.7** | −8.0** | −1.19| −0.54| −0.27| −0.31| −0.11| 1010.7***| −740.9***|
| L3   | −7.7** | −2.9*  | −1.52| −0.71| −0.44| −0.06| 0.39 | −659.4***| −2433.9***|
| L4   | 22.8***| 17.5***| 1.98| 1.79 | 1.73 | 0.19 | −0.53| 467.0***| 529.0***|
| L5   | 8.3**  | −5.5** | 1.31| 0.46 | 3.23 | 0.02 | −0.28| 143.8***| −317.7***|
| L6   | 9.8**  | 2.6*   | −0.69| −0.71| 1.39 | −0.15| 0.55 | −474.0***| −4550.0***|
| L7   | 9.7    | 8.0**  | 0.98| 0.96 | −1.10| 0.19 | 0.55 | 72.0***| 2222.3***|
| L8   | −16.5***| −5.2** | −1.69| −2.21| −3.44| −0.06| −0.03| −631.7***| 12381.0***|

| TESTER |        |        |     |      |      |      |      |       |       |
|--------|--------|--------|-----|------|------|------|------|-------|-------|
| T1     | 0.67   | 3.8    | 0.02| 0.08 | 0.69 | 0.13 | −0.05| −62.7***| 2751.3***|
| T2     | −0.67  | −3.8   | −0.02| −0.08| −0.69| −0.13| 0.05 | 62.7***| −2751.3***|
Table 5. Specific combining ability of 16 three-way crosses for yield and yield-related traits Adet

| LINE | TESTER | PH  | EH  | DST | DSS | MD  | PAS | EAS  | GY         | CN         |
|------|--------|-----|-----|-----|-----|-----|-----|------|------------|------------|
| L1   | T1     | -6.8| -6.8| 0.98| 0.25| 0.65| 0.38| 0.64 | 1044.7***  | -5291.0*** |
| L1   | T2     | 6.8 | 6.8 | -0.98| -0.25| -0.65| -0.38| -0.64| -1044.7*** | 5291.0***  |
| L2   | T1     | 5.3 | 7.4 | 0.65| 0.42| -0.52| -0.13| -0.28| 923.3***   | 2751.2***  |
| L2   | T2     | -5.3| -7.4| -0.65| -0.42| 0.52 | 0.13 | 0.28 | -923.3***  | -2751.2*** |
| L3   | T1     | 4.3 | 1.6 | 0.35| -0.42| 0.65 | 0.13| -0.28| -812.4***  | -3174.5*** |
| L3   | T2     | -4.3| -1.6| -0.35| 0.42 | -0.65| -0.13| 0.28 | 814.4***   | 3174.5***  |
| L4   | T1     | -5.8| -9.4| -2.85| -2.92| -0.85| -0.46| 0.14 | -410.7***  | 3174.7***  |
| L4   | T2     | 5.8 | 9.4 | 2.85| 2.92| 0.85 | 0.46| -0.14| 410.7***   | -3174.7*** |
| L5   | T1     | -3.7| -4.4| -0.85| -0.58| -0.02| -0.13| -0.28| 16.7***    | 1481.4***  |
| L5   | T2     | 3.7 | 4.4 | 0.85| 0.58 | 0.02 | 0.13| 0.28 | -16.7***   | -1481.4*** |
| L6   | T1     | -7.2| -1.9| -0.52| -0.42| 0.48 | 0.42| 0.05 | -228.9***  | 635.0***   |
| L6   | T2     | 7.2 | 1.9 | 0.52| 0.42 | -0.48| -0.42| -0.05| 228.9***   | -635.0***  |
| L7   | T1     | 4.7 | 6.7 | 0.81| 0.58 | 0.65| 0.42| 0.05 | 567.3***   | 5714.0***  |
| L7   | T2     | -4.7| -6.7| -0.81| -0.58| -0.65| -0.42| -0.05| -567.3***  | -5714.0*** |
| L8   | T1     | 9.2 | 6.9 | 2.15| 3.08| -1.02| 0.13| -0.03| -1100.2*** | -5291.0*** |
| L8   | T2     | -9.2| -6.9| -2.15| -3.08| 1.02| -0.13| 0.03 | 1100.2***  | 5291.0***  |
Nepir, Wegary, and Zeleke (2015) also expressed that heterotic group could be discriminated only by the significant SCA effects. Results in this study showed that four hybrids combinations revealed positive significant SCA effects for grain yield with tester A but the rest four expressed negative SCA effects with the same tester and vice versa with tester B indicated four lines (L1, L2, L5 and L7) were grouped into heterotic group A and the remaining four lines (L3, L4, L6 and L8) were classified into heterotic group B (Table 6).

Maximum genetic variability and hybrid vigor (heterosis) can be exploited by crossing lines from different heterotic groups. Lines in the same heterotic group accompanied by desirable GCA effects can be used for the development of synthetic varieties. Chemada et al. (2015), Dufera et al. (2018) and Legesse et al. (2014) classified lines into different heterotic groups using the direction of SCA effects for grain yield.

### 4. Conclusion and recommendation

Exploitation of hybrid vigor and selection of parents require information on the magnitude of useful genetic variances present in the genotypes in terms of combining ability and association of components.

Combining ability analysis is a useful genetic means to estimate GCA of parents and SCA of crosses to select the desired parents and crosses. Analysis of variance indicated genetic variation among genotypes by revealing significant differences between genotypes for most studied traits. Significant differences between parents (lines and testers) and interactions of parents and crosses for most traits indicated wide range of variability present among them. Three hybrids H3 (10481 kg ha\(^{-1}\)), H1 (9663 kg ha\(^{-1}\)) and H8 (9550 kg ha\(^{-1}\)) showed better performance in grain yield compared to standard check AMH-851(Jibate).

Information regarding combining ability is very important to select desirable parents and crosses. GCA analysis identified inbred lines L1, L2, L4, L5, L7 and tester CML-442/CML-312 as good general combiners for grain yield. SCA effect analysis recognized that eight three-way crosses were good specific combiners for grain yield. Heterotic grouping classified four lines (L1, L2, L5 and L7) into heterotic group A and the remaining four lines (L3, L4, L6 and L8) into heterotic group B. In general, the present investigation approved that inbred lines with good GCA, cross-combinations with desirable SCA and classification of lines into different heterotic groups. So desirable hybrids can be developed by crossing lines from different heterotic group and synthetic varieties can be produced by using lines with good GCA effects within a heterotic group. Additionally, cross-combinations with desirable SCA effects and better yield performance would be tested in multi-location trial to identify better-performing cross(es) among them.

### Table 6. Heterotic grouping based on specific combining ability and grain yield at Adet

| LINE | GY (kg ha\(^{-1}\)) | SCA GY (kg ha\(^{-1}\)) | SCA Heterotic group |
|------|-----------------|------------------------|---------------------|
| L1   | 9663            | 1044.7***              | 7700 –1044.7***     | A       |
| L2   | 10481           | 923.3***               | 8760 –923.3***      | A       |
| L3   | 7075            | –812.4***              | 8826 812.4***       | A       |
| L4   | 8603            | –410.7***              | 9550 410.7***       | B       |
| L5   | 8708            | 16.7***                | 8800 –16.7***       | A       |
| L6   | 7844            | –228.9***              | 8428 228.9***       | B       |
| L7   | 9187            | 567.7***               | 8177 –567.7***      | A       |
| L8   | 6815            | –1100.2***             | 9141 1100.2***      | B       |
Funding
The authors received no direct funding for this research.

Competing Interests
The authors declare no competing interests.

Author details
Melkamu Elmyhun 1
E-mail: elmyhunm@gmail.com
Chale Liyew 2
E-mail: elmyhunmelkamu@yahoo.com
Abyneh Shita 3
E-mail: shitaaboayneh@gmail.com
Mekuanint Andualem 1
E-mail: mekuanint09@gmail.com
1 Amhara Regional Agricultural Research Institute, Aдет Agricultural Research Center, Bahir dar, Ethiopia.

Citation information
Cite this article as: Combining ability performance and heterotic grouping of maize (Zea mays) inbred lines in testcross formation in Western Amhara, North West Ethiopia, Melkamu Elmyhun, Chale Liyew, Abyneh Shita & Mekuanint Andualem, Cogent Food & Agriculture (2020), 6: 1727625.

References
Abebe, A., Wolde, L., & Gebreceslassie, W. (2018). Combining ability and heterosis of maize inbred lines. Ahmad, D. Z., Ahmed, L. A., Hussain, W. S., Bashir, A., Ishfaq, A., Gowhar, A., … Atif, W. M. (2017). Analysis of combining ability in maize (Zea mays L) under temperate conditions. International Journal of Agriculture Sciences, 9(2), 3647–3649.
Ahmed, S., Begum, S., Islam, A., Ratna, M., & Karim, R. (2018). Combining ability estimates in maize (Zea Mays L.) through Line × tester analysis. Bangladesh Journal of Agricultural Research, 42(3), 425–436. doi:10.3329/bjar.v42i3.34501
Aliu, S., Fetohu, S., & Sailllari, A. (2008). Estimation of heterosis and combining ability in maize (Zea mays L.) for ear weight (ew) using the diallel crossing method. Latvian Journal of Agronomy,11(1), 7–12.
Andayani, N. N., Azil, M., Roy Efendi, R., & Azrai, M. (2018). Line × tester analysis across equatorial environments to study combining ability of indonesian maize inbred. Asian J Agri & Biol, 6(2), 213–220.
Aslam, M., Sohail, Q., Maqbool, M. A., Ahmad, S., & Shoaib, R. (2017). Combining ability analysis for yield traits in diallel crosses of maize. Journal of Animal and Plant Sciences, 27(1), 136–143.
Central Statistical Agency (CSA). (2018). Central statistical agency, Ethiopian agricultural sample survey for 2017/2018. Addis Ababa, Ethiopia: Central Statistical Agency.
Ceyhan, E. (2003). Determination of some agricultural characters and their heredity through line x tester method in pea parents and crosses. Selcuk University Graduate School of Natural & Applied Science,10(2), 130.
Chemado, G., Alamerew, S., Tadesse, B., & Menamo, T. (2015). Test cross performance and combining ability of maize (Zea mays L.) inbred lines at Bako, Western Ethiopia. Global Journal of Science Frontier Research, 15(6), 1–24.
Dufero, T., Bulti, T., & Girum, A. (2018). Heterosis and combining ability analysis of quality protein maize (Zea mays L). Inbred Lines Adapted to Mid-altitude Sub-Humid Agro-ecology of Ethiopia. Afr. J. Plant Sci, 12(5), 47–57.
Gichuru, L., Njorog, K., Ininda, J., & Peter, L. (2011). Combining ability of grain yield and agronomic traits in diverse maize lines with maize streak virus resistance for Eastern Africa region faculty of agriculture, University of Nairobi. Agriculture and Biology Journal of North America, 2(3), 432–439. doi:10.5251/abjna.2011.2.3.432-439
Griffing, B. (1956). Concept of general combining ability and specific combining ability in relation to diallel crossing system. Australian Journal of Biological Sciences, 9, 463–493. doi:10.1071/BJ9560463
Hallauer, A. R., & Miranda, J. B. (1988). Quantitative genetics in maize breeding (2nd ed.). Ames: Iowa State University Press.
Kanyamissoro, M. G., Karungi, J., Asea, G., & Gibson, P. (2012). Determination of the heterotic groups of maize inbred lines and the inheritance of their resistance to the maize weevil. African Crop Science Journal, 20(1), 99–104.
Kosari, A. N. M. S., Ahmed, S., Akhi, A. H., Talukder, M. Z. A., & Mujahid, T. A. (2018). Combining ability and heterosis study in maize (Zea mays L) hybrids at different environments in Bangladesh. Bangladesh Journal of Agricultural Research, 43(1), 125–134. doi:10.3329/bjar.v43i1.36186
Kempthorne, O. (1957). An introduction of genetics statistics. New York, NY: John Wiley and Sons.
Kumar, A., Dadheech, A., Kiron1, N., Bisen, P. and Santosh Kumar, S. (2017). Diallel Analysis of Combining Ability for Yield and Yield Contributing Traits over the Environments in Maize (Zea mays L). Int.J.Curr. Microbiol.App.Sci, 6(10), 196–208.
Kuselam, K., Manivannan, N., Ravikesavan, R., Parandihvaran, V., & Gupta, R. (2017). Combining ability of maize inbreds for yield and component traits in multi environment diallel analysis. Int. J. pure appl. biosci,5(6), 725–729.
Legesse, W., Mosisa, W., Berhanu, T., Girum, A., Wende, A., Solomon, A., & Tola, K., … Andualem, W., & Belayneh, A. (2014). Genetic improvement of maize for mid-altitude and lowland subhumid agro-ecologies of Ethiopia. In Worku, M., S. Twumasi-Afriyie, … B. M. Prasanna, (Eds.), (Vol. 57, pp. 17–23). Agricultural Research Center, Bahir dar, Ethiopia.
Matin, M. Q. I., Rasul, M. G., Islam, A. K. M. A., Mian, M. A. K., Ily, N. A., & Ahmed, J. U. (2016). Combining Ability and Heterosis in Maize (Zea mays L). American J. Bio Sci, 4(6), 84–90.
Mosisa, W., Legesse, W., Berhanu, T., Girum, A., Wende, A., … Getachew, B. (2015). Status and future direction of maize research and production in Ethiopia (pp. 17–23). Addis Ababa, Ethiopia.
Natal, B. (2017). Combining ability and heterotic grouping in maize (Zea Mays L.) inbred lines for yield and yield related traits. World Journal of Agricultural Sciences, 13(6), 212–219.
Nepir, G., Wegary, D., & Zeleke, H. (2015). Heterosis and combining ability of highland quality protein maize inbred lines. Maydica, 60, 1–12.
Parentoni, M. E. A. G. Z., Sawazaki, E., Duarte, A. P., & Gallo, P. B. (2001). Diallel crosses among maize lines with emphasis on resistance to foliar diseases. Genetics and Molecular Biology, 23, 381–385.
Rawi. (2016). Relative performance and combining ability for yield and yield components in maize by using full diallel cross. International Journal of Current Research, 8(9), 37721–37728.
Shah, L., Rahman, H. U., Ali, A., Bazai, N. A., & Tahir, M. (2015). Combining Ability estimates from line x tester mating design in maize (Zea mays L). Academic Research Journal of Agricultural Science and Research, 3(4), 71–75.
Singh, R. K., & Chaudhary, R. D. (1979). Biometrical methods in quantitative genetic analysis, Kalyani Publ. Sousa JA de, Maluf WR, p. 20. New Delhi.

Sprague, G. F., & Tatum, L. A. (1942). General vs. specific combining ability in single crosses of corn. Agronomy Journal, 34, 923–932. doi:10.2134/agronj1942.00021962003400100008x

United States Department of Agriculture (USDA). (2018). World agricultural production. Foreign Agricultural Service. Rome.

Vasal, S. K., Srinivasan, G., Han, G. C., & Gonzales, C. F. (1992). Heterotic patterns of eighty-eight white subtropical cimmyt maize lines. Maydica, 37, 319–327.

Worku, M., Abdurahaman, J., Tulu, L., Tuna, H., Wolde, L., Yihun, K., ... Zeleke, H. (2002). Improved germplasm development for the mid and low altitude sub-humid agro-ecologies of Ethiopia. Journal of Immunological Methods, 267, 27–30. doi:10.1016/s0022-1759(02)00138-2

World Food and Agriculture Organization (FAO). (2019). World food and agriculture – Statistical pocketbook 2019 (pp. 254). Rome. License: CC BY-NC-SA 3.0 IGO.