allel_of_F1_Tomato_Hybrid_and _its_Double_Cross-Compatibility.pdf

by

BIODIVERSITAS
Volume 23, Number 4, April 2022
Pages: 1813-1821

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230413

Half diallel of F1 tomato hybrid and its double cross-compatibility

MUH FARID♥, MUHAMMAD FUAD ANHSORI♥♥, IFAYANTI RIDWAN, NOVATY ENY DUNGGA, IRNA ERMIYANTI

Department of Agronomy, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia. Tel.: +62-411-586014, ♥email: farid_deni@yahoo.co.id; ♥♥email: fuad.pbt15@gmail.com

Manuscript received: 19 November 2021. Revision accepted: 17 March 2022.

Abstract. *Farid M, Anhsori MF, Ridwan I, Dungga NE, Ermiyanti I. 2022. Half diallel of F1 tomato hybrid and its double cross-compatibility. Biodiversitas 23: 1813-1821.* Breeding program for improvement of tomato fruit can be done through diallelic crosses genetic combinations. Therefore, genetic evaluation is needed to meet the breeding objective. This process can be combined with crosses between F1 to produce high diversity. However, evaluating the crosses' compatibility is required to increase the effectiveness of the assembly process. This study aimed to assess the half-diallel crosses of F1 tomatoes in the field and determine the most compatible pair cross combinations in forming double and three-way F1 populations. This study was carried out in the Experimental Farm of the Faculty of Agriculture, Hasanuddin University. The field evaluation was arranged in a randomized complete block design with ten genotypes, while the compatibility evaluation was carried out using 6 F1 half diallel as the parents. The results showed that the Mawar and Chung varieties were better parents in the crossings. Furthermore, the results showed that F1 K/M (the best yield component), M/C (the best TDS and Lycopene traits), and BC/K (the genotype has good traits of yield component, TDS and Lycopene) were the best single F1 crosses that could be inherited to the F2 generation. In contrast, F1 K/M and F1 K/C crosses were the best male and female parents, respectively. The recommended double-crosses include K/C//BC/M, and BC/C//K/M, while for the F1 unbalanced three-way cross was K/C//K/M.

Keywords: Compatible ability, diallel mating, double-cross, hybrid tomato, *Solanum lycopersicum*

Abbreviations: BC: Blackcherry, C: Chung, K: Karina, M: Rose, FD: fruit diameter, FL: fruit length, TDS: total dissolved solids, FW: fruit weight, L: lycopene, NBP: number of bunches per plant, NFB: number of flowers per bunch, NFpB: number of fruits per bunch, SD: stem diameter

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill) is one of the food products that are rich in natural antioxidants. It has good antioxidant content, specifically lycopene, which improves the immunity of the human body (Elbadrawy and Sello 2016; Fraser et al. 2020; Przybylska 2020). The antioxidant content in tomatoes has a variety of health benefits and diverse nutritional content such as fiber, carbohydrates, vitamins, minerals, and protein and fat (Raiola et al. 2015; Leiva-Brondo et al. 2016; Campestrini et al. 2019). These benefits have made the fruits highly demanded by the public (Fentik 2017; Chaudhary et al. 2019). However, the growth of tomatoes production is considered slow. According to the statistics of Indonesia (2021), the average growth increase of this fruit is 5.13%. Therefore, developing the productivity and quality of tomatoes in line with the population rate is one of the keys to stabilizing the rate of production and demand.

One of the main problems of tomato cultivation in Indonesia is the lack of high-yielding superior varieties with good fruit quality and resistance to pests and diseases (Suyadi and Rosfiansyah 2017; Schreinemachers et al. 2018; Piosik et al. 2019; Oliveira et al. 2020; Afifah et al. 2021). Therefore, efforts to obtain superior varieties need to be carried out, both with conventional and breeding methods such as crosses (Holme et al. 2019; Campanelli et al. 2019; Avdikos et al. 2021), mutation breeding, and genetic engineering (Ayenan et al. 2019; Chaudhary et al. 2019; Cappetta et al. 2020; Afifah et al. 2021; Breitel et al. 2021; Salava et al. 2021). In addition, due to the various benefits of tomatoes, more improvement needs to be carried out on the plant in terms of productivity, fruit quality, resistance to plant pest organisms, and tolerance to various environmental stresses (Acquaah 2012). Therefore, the plant crosses are required to obtain adaptive and high-quality tomatoes that meet consumers' preferences. Furthermore, according to Mustafa et al. (2019), the assembly of different varieties through crossing can induce the dominant and overdominant gene action based on the desired traits. This gene action would be able to create lines that are better than their parents and be effective in improving the crop.

The crossing methods strongly influence the formation of tomato diversity. Examples include single, double, three-way, multiple, backcrosses, and diallel mating. Diallel mating is a crossing technique that creates a high diversity of crosses (Olfati et al. 2012; Zeinab and Helal 2014; Murtadha et al. 2018; Mat et al. 2020). This high diversity serves as an equal opportunity for each parent to be crossed with each other; hence, the number of possible crosses can be the combinatorics of all the parents involved (Olfati et al. 2012; Bouchetat and Aissat 2019; Mat et al. 2020). In addition, this analysis can be used to explore genetic parameters in detail, both on genetic diversity, heritability, gene action, and combining ability (Syukur et al. 2010; Ghareeb and Fares. 2016; Ene et al. 2018; Zongo et al. 2019). These advantages have made this method commonly used by many breeders (Syukur et al. 2010; Bahari et al. 2011; Murtadha et al. 2018; Zongo et al. 2019; Mat et al. 2020). However, diallel crosses do not necessarily involve all possible combinations (full diallel). Some studies also use the concept of half diallel because it involves the use of several combinations of pure line parents in the absence of their reciprocals (Olfati et al. 2012; Ene et al. 2018; Boyaci et al. 2020; Dianga et al. 2020; Datta et al. 2021). Although this combination is not as much as in full diallel crosses, this method is quite effective for a small number of parents and focuses on the nature of cross interactions that do not involve maternal effects (Singh and Chaudhary 1979; Olfati et al. 2012; Datta et al. 2021). This would help in minimizing the error effect of the coupling test. Based on Bdr et al. (2020), 6 F1 results from half diallel crosses from 4 parents (Black Cherry, Karina, Mawar, and Chung) need to be evaluated and increased for their diversity. The increase in the diversity of the F1 will be correlated with the chances of superior offspring formation to meet the breeder's expectations. Furthermore, this can be performed by double-crossing between F1 hybrids.

Double crosses can create greater population diversity than single cross F1 (Acquaah 2012; Muthoni and Shimelis 2020; Joshi and Gautam 2021). This concept is crucial in producing adaptive tomato varieties that suit consumer expectations (Campanelli et al. 2019; Matos et al. 2021). These double-cross from the half-diallel single cross can be combined with diallel mating, and this concept has been reported by Matos et al. (2021). Furthermore, the combination from half diallel can form F1 double and unbalanced three-way crosses. Both population concepts can increase the opportunity to develop tomato genotypes with high productivity and good fruit quality. Furthermore, the combination of these crosses is also determined by their compatibility (Deprá et al. 2014; Farid et al. 2021). However, because tomato plants are self-pollinating, the success of crosses is relatively more difficult (Deprá et al. 2014; Piosik et al. 2019). Therefore, it is also important to observe the cross-compatibility to increase the effectiveness of crosses between F1. This study aimed to evaluate the half-diallel crosses of F1 tomatoes in the field based on agronomy and lycopene characters and determine the best compatible pair crosses to form either double or unbalanced three-way F1 population.

MATERIALS AND METHODS

The study was carried out in the Experimental Farm of the Faculty of Agriculture, Hasanuddin University, Tamalanrea District, Makassar City, South Sulawesi, Indonesia from March to November 2021. The location is 22.4 m above sea level with an average minimum and maximum temperature of 24°C and 32°C, respectively. Two experiments were conducted simultaneously on different farm sites with different methods.

F1 hybrid evaluation

This first experiment evaluated the diversity of tomato F1 hybrids using a randomized complete block design (RCBD) with three replications. In addition, ten genotypes consisting of 6 combinations of F1 half diallel crosses were used to focus on the productivity and lycopene traits (Chung x Mawar, Karina x Mawar, Black Cherry x Mawar, Karina x Chung, Black Cherry x Chung, Black Cherry x Karina) of the four parents, namely, Karina (oval fruit shape and good productivity), Mawar (wavy fruit shape and good productivity), Black Cherry (round fruit shape and high lycopene) and Chung (little round fruit and high lycopene). Therefore, there were 30 experimental plot units with ten plant samples based on this experiment.

Double cross-compatibility trial

The double-cross and compatibility experiments were carried out between F1 single crosses with the concept of a diallelic cross, using six parents, each of which had five plants, bringing 30 crosses. The crossing process for each cross combination was carried out 30 times to produce 900 crosses units.

Study implementation

Seeding was conducted previously in a GreenHouse to control the seedlings easily. The planting medium used was a ratio of 1:1 roasted husk and compost. Before planting, the planting medium was irrigated to field capacity level and then applied with Furadan to avoid interference or pest attacks. At 7 DAS, they were given ABmix solution with a dose of 5 mL per Liter of water around the plant roots. The seedlings were then transplanted into pots or polybags about 14 days after sowing (DAS).

Transplanting was conducted by transferring tomato seedlings about two to three weeks after planting (WAP) to the bed. The beds were made with a width of 80 cm and a length of 2.5 m with a distance of 30 cm. The beds were covered with black silver plastic mulch, and the planting holes were made by perforating the plastic using a 10 cm diameter can. The spacing used was 60 cm and 80 cm in and between rows. Furthermore, the spacing affects the humidity level around the plant, the level of soil nutrients used, the level of pathogen development, such as pests, fungi, viruses, and bacteria, and the intensity of sunlight reception.

Plant maintenance included watering, replanting, fertilizing, pruning, weeding, and controlling pests and diseases. Watering was performed twice a day in the morning and evening using a watering can or sprinklers. Unhealthy seedlings we replaced with new healthy ones. Fertilization was carried out one WAP, while the next was given once a week. Fertilization was carried out using NPK Mutiara fertilizer (16:16:16) at 250 mL application solution per plant with 10 g L^{-1} of water. At the next fertilization KNO_3 at a dose of 5 g L^{-1} was added. In addition, NPK Mutiara was given in the form of a solution applied around the plant roots during the reproductive phase, while

Gandasil B (6% Nitrogen, 20% Phosphate, 30% Potassium and 3% Magnesium) was used during the generative phase. Pruning was conducted at least once a week to remove the initial or small shoots on the lower stem and on other shoots to direct the growth of the tomatoes to the main stem. In addition, weeding was carried out manually.

Prevention and control of pests and plant diseases were carried out once a week using a mixture of Curacron 500 E and fungicide Antracol 70 WP C with a concentration of 2 cc L^{-1} and 2 g L^{-1} of water. This application was also combined with Dhitane M-45 WP and a concentration of 2 g L^{-1} of water in place of the fungicide Antracol 70 WP to get more effective control. Pesticides were applied by spraying the plant surface and harvesting twice a week. The fruits ready for harvest were those that had a reddish-yellow color.

Tomato plant crossings processes

Crosses were conducted using all possible combinations among a group of parent materials. The crossings were carried out as follows. Preparation: This process includes preparing the equipment needed, crossing the tomatoes, knowing the morphology and phenology of the plants, and selecting the best female and male elders to be crossed. Castration is cleaning or removing plant parts around the flowers to be emasculated from dirt, insects, unused flower buds, other plant organs that interfere with crosses, and the disposal of crowns and petals on tomato plants. Emasculation is removing the male genitalia (stamen) on the female parent to be crossed. The emasculation method used in this study of tomato crosses was the clipping or tweezers. Pollen collection involves taking pollen from previously selected male parents. The tool used to take pollen was a needle or tweezers. Pollination is the process of putting pollen that has been taken from the male parent to the stigma of the female parent. Isolation, confinement is the activity of covering the flowers of the female parent crossed using a cover or others to avoid un-wanted crosses/pollination. Finally, labeling was conducted by providing information on the breeder's name and parent of the cross and the date to facilitate the identification of the cross fruit.

Observation

Quantitative parameters of F1

The quantitative characters observed was based on Ermiyanti et al. (2021), namely, plant height (cm), days to flowering (DF) and harvesting (DH), stem diameter (cm), number of bunches per plant (bunch), number of flowers per bunches (flowers), number of fruits per bunch (fruit), fruit length (cm) and diameter (cm), total dissolved solids (brix), fruit weight (g), fresh fruit yield (ton ha^{-1}), and lycopene content. The analysis of lycopene content was based on Bdr et al. (2020).

F1 double cross-compatibility parameters

The quantitative characters observed were fruit crossing success per plant, the fruit diameter (cm), fruit flesh thickness (cm), fruit length (cm), total dissolved solids (brix), as well as average weight and number of seeds per fruit.

Data analysis

The field evaluation data were subjected to analysis of variance (ANOVA) using Griffing method II (Sigh and Chaudary 1979). Hybrid with a significant effect was further evaluated for both general and specific combining ability. The GCA LSD was commonly compared among the parents using SE GCA. For SCA, there were two methods. If the hybrid was compared with the same female parent, LSD used SE (Sii-Sij).

Meanwhile, if the hybrid was compared with another female, LSD used SE (Sii-Sik). Then, if the hybrid was compared with another female parent, LSD used SE (Sii-Sij). The cross-pollination full diallel was analyzed with success percentage. Furthermore, its fruit characters of result crossing were analyzed with ANOVA through Griffing method I (Sigh and Chaudary 1979). The Griffing ANOVA used Software Pbtools 1.4 from IRRI (Bartolome et al. 2014).

RESULTS AND DISCUSSION

ANOVA and genetic components

The interaction between parent 1 (P1) and parent 2 (P2) on tomato growth significantly affected all plant characters. General combining ability (GCA) significantly affected days to flowering, days to harvesting, number of bunches per plant, total dissolved solids, number of flowers per bunch, fruit diameter, total dissolved solids, and yield. Meanwhile, specific combining ability (SCA) had a highly significant effect on almost all observed characters, except the days to harvest (Tables 1 and 2).

The days to harvesting, stem diameter, number of bunches per plant, fruit diameter, total dissolved solids, and yield showed an A/D ratio of >1.0. Meanwhile, the A/D ratio of <1 was found on plant height, DH, number of flowers and fruits per bunch, length, lycopene, and fruit weight. All tomato growth characters with broad-sense heritability values (H^2) were high. On the other hand, almost all the characters had a narrow sense heritability value (h^2) of < 0.5, except DH (0.72), total dissolved solids (0.85), and yield (0.6).

GCA and SCA of the tomato growth characters

The GCA and SCA of several significantly affected growth characters are presented in Tables 3 and 4. The lowest GCA of DF was shown by the Cung parents (-7.84), while Blackcerry had the highest score (7.21). Based on the DH parameter, the lowest GCA value was found in the Cung parents (-2.01) and not significantly different from the Mawar variety (-1.92). Furthermore, Karina's parents had the highest GCA value of 2.03, but it was not substantially different from Blackcerry (1.90). The best GCA value was found in Cung parents (2.12) and not significantly different from Mawar (1.12) for the number of bunches per plant. The Mawar parents had the highest GCA of fruit diameter and yield value of 0.54 and 0.87, respectively. In addition, for total dissolved solids, the highest GCA value was from Blackcerry (1.18) and not significantly different from Karina (0.04).

The results of the specific combining ability are shown in Tables 3 and 4. Based on characters that SCA only influenced, the best hybrid genotype SCA values on plant height, stem diameter, number of flowers, fruit length, fruit weight, lycopene characters were BC/K (15.53), K/M (0.23), M/C hybrid (3.10), K/M hybrid (1.59), K/M hybrid (13.29), and BC/K (5.03), respectively. All these hybrids have significant differences with the Blackcherry variety. Based on characters that have significance in SCA and GCA, the best hybrid genotype SCA values on the number of fruits per bunch, fruit diameter, total dissolved solids content, and yield are M/C hybrid (1.37), BC/C hybrid (0.95), K/C (0.42), and K/M hybrid (4.40), respectively. All these hybrids also have significant differences with the Blackcherry variety. On the other hand, the lowest SCA of DF trait was observed on BC/M (-3.95).

Compatibility analysis of double cross among F1 tomato half diallel

The results of the tomato crossing compatibility analysis showed that the F1 K/C hybrid was the best female parent (35.00%), while K/M hybrid was the best male parent (31.33%) (Table 5). K/C//BC/K and K/C//BC/C double-cross hybrids showed the high percentage level of compatibility of multiple crosses with a percentage of 43.33% and 40%, respectively. In addition, the lowest percentage level of cross-compatibility was shown by double-cross hybrids BC/C//K/C, BC/C//M/C, and K/M//BC/M, each with 13.33% level of compatibility (Table 5).

The GCA of double cross based on fruit characters

The results of GCA analysis for fruit diameter, length, thickness, weight and cavity, total dissolved solids, and the number of seeds were presented in Table 6. The best GCA values for the characters of fruit diameter and length, total dissolved solids, were shown by, respectively, F1 K/C (3.75), F1 K/M (7.13), F1 BC/C (0.53), and BC/M (1.14). As for the fruit thickness, cavities, and last character, the best GCA values were shown by K/M (3.63), BC/K (0.12), and F1 K/C (6.63); however, it was not significantly different from that of K/C (3.38), M/C hybrids (0.10), and K/M hybrids (5.88).

Table 1. Results of ANOVA and genetic components of vegetative and inflorescence characters

SV	PH	DF	DH	SD	NBP	NFB
P1:P2	233.02**	347.72**	37.00**	2.24**	38.19**	13.34**
Residual	67.46	10.15	4.97	0.29	2.88	2.11
GCA	37.85^{ns}	241.60**	30.84**	1.48^{ns}	24.66**	6.85^{ns}
SCA	97.59**	53.06**	3.08^{ns}	0.38**	6.77**	3.25**
Error	21.07	3.33	1.66	0.09	0.96	0.70
Variance of additives effect (A)	0.00	125.69	18.50	0.36	5.97	1.20
Variance of dominant effect (D)	76.52	198.91	5.70	0.30	5.80	2.54
Ratio of A/D	0.00	0.63	3.25	1.20	1.03	0.47
h^2 (Broad Sense)	0.78	0.99	0.94	0.88	0.92	0.84
h^2 (Narrow Sense)	0.00	0.38	0.72	0.48	0.47	0.27

Note: **Highly significant at 1% level (P<0.01), *Significantly influential at 5% level (0.01≤P<0.05), ns: Not significant (P≥0.05), SV: sources of variation, PH: plant height PH, DF: days to flowering, DH: days to harvest, SD: stem diameter, NBP: number of bunches per plant, NFB: number of flowers per bunch

Table 2. Results of ANOVA and genetic components of fruit and yield characters

SV	NFpB	FD	FL	TDS	FW	Yield	L
P1:P2	3.54**	2.25**	5.04**	4.80**	378.04**	313.99**	48.79**
Residual	0.33	0.29	0.16	0.10	1.22	0.45	1.56
GCA	1.29^{ns}	1.47**	3.03^{ns}	4.33**	155.40^{ns}	230.97**	15.97^{ns}
SCA	1.12**	0.39**	1.01**	0.23**	111.32**	41.51**	16.41**
Error	0.11	0.09	0.05	0.03	0.38	0.14	0.52
Variety of additives (A)	0.06	0.36	0.67	1.37	14.69	63.15	0.00
Dominant Variety (D)	1.01	0.30	0.96	0.20	110.95	41.37	15.89
Variety A/D	0.06	1.20	0.70	6.85	0.13	1.53	0.00
H2 (Broad Meaning)	0.91	0.88	0.97	0.98	1.00	1.00	0.97
h2 (Narrow Meaning)	0.05	0.48	0.40	0.85	0.12	0.60	0.00

Note: **Significantly influential at 1% level (P<0.01); *Significantly influential at 5% level (0.01≤P<0.05); ns: not significant (P≥0.05), SV: sources of variation, NFpB: number of fruits per bunch, FD: fruit diameter, FL: fruit length, TDS: total dissolved solids, FW: fruit weight, L: lycopene

Discussion

Evaluation of half diallel

ANOVA on the half diallelic showed a significant effect on all characters, indicating that the half diallelic concept was effective. The effectiveness of using the half diallelic mating design was also reported by Pandiarana et al. (2015); Kumar and Paliwal (2016); Kaushik and Dhaliwal (2018); and Vijeth et al. (2019) on tomatoes, Boyaci et al. (2020) and Datta et al. (2021) on eggplant, and Dianga et al. (2020) on rice. Based on these studies, an in-depth analysis of genetic parameters, namely heritability, gene action, and combining ability, can be determined.

Heritability is a commonly identified genetic parameter that describes the magnitude of the genetic diversity's proportion to phenotypic diversity (Acquaah 2012; Fikere et al. 2020; Barreto et al. 2021). Therefore, it has become one of the bases in determining the effectiveness of selecting and assessing a population (Munene et al. 2018; Parkes et al. 2020; Kaur et al. 2021). Specifically, the heritability approach is divided into two; the broad and narrow senses of heritability. The broad-sense approach indicates the general genetic influence of a population on the diversity of its phenotypic traits. Furthermore, the narrow-sense approach emphasizes the effect of inherited gamete diversity on the phenotypic diversity of a population (Acquaah 2012; Ogunniyan and Olakojo 2015; Mistry et al. 2016; Mawasid et al. 2019; Kumar and Srivastava 2021). Based on the results of this study, it was found that all characters had high broad-sense heritability. However, these high broad-sense heritabilities are not supported by the total dissolved solids and the yield that still showed high narrow-sense heritability. This indicates that the phenotype of the characters is dominated by its genetic influence and can be passed on to the next generation, specifically the total dissolved solids and yield. Evaluation of crosses based on the heritability of tomatoes was also reported by Amaefula et al. (2014), Mawasid et al. (2019), Florido-Bacallao et al. (2021), and Kumar and Srivastava (2021). Therefore, the assessment of crosses in this study was effective.

Gene action is one of the genetic parameters that determine the pattern of gene control for a trait and can also be used to provide information on the pattern and direction of selecting a cross method (Zeinab and Helal 2014; Mistry et al. 2016; Ene et al. 2018; Farooq et al. 2019; Zongo et al. 2019). In general, gene action is divided into additive and non-additive (Kaushik and Dhaliwal 2018; Farooq et al. 2019; Zongo et al. 2019; Dianga et al. 2020). The additive action of this gene is identical to the ability of inherited gametes to control a particular trait (Acquaah 2012; Zeinab and Helal 2014; Vijeth et al. 2019). Meanwhile, the non-additive gene action is identical to allele interactions, both within the same locus and between different loci, while controlling a trait (Acquaah 2012; Hakim and Suyamto 2017; Hivert et al. 2021). This can be in the form of dominance, over-dominance, and epistatic gene action (Acquaah 2012; Nugraha et al. 2016). According to Marwiyah et al. (2019), Dianga et al. (2020), and Datta et al. (2021), the determination of gene action can be carried out by ratios or comparisons of additive and dominant diversity. A ratio of more than 1 indicates that the character is more dominated by additive gene action while a ratio of less than 1 shows that it is influenced by the dominant gene action. Based on this study, the number of characters controlled by additive gene action had relatively the same with non-additive gene action; therefore, genotypes with high GCA and SCA will have good progeny vigor when crossed with other genotypes with characters that are controlled by non-additive gene action. However, the determination of the concept of selection from this study can be directed towards its primary objective. When it's based on productivity, the selection pattern used will lead to the action of the additive gene. This has also been reported by Pandiarana et al. (2015), Kaushik and Dhaliwal (2018), and Vijeth et al. (2019). Furthermore, when the selection is focused on the lycopene trait, the pattern used will lead to the non-additive gene's action, which is in line with Pandiarana et al. (2015). Cross-examination is also required while identifying the pattern of gene action reflected while combining different parameters.

Combining ability is a parameter that describes the ability of a genotype when crossed with other genotypes (Zeinab and Helal 2014; Murtadha et al. 2018; Marwiyah et al. 2019). This is closely related to the pattern of gene action; therefore, it is divided into two types, namely GCA and SCA (Pandiarana et al. 2015; Ghareeb and Fares 2016; Kaushik and Dhaliwal 2018; Farooq et al. 2019; Vijeth et al. 2019). GCA is identical abilities for additive gene action, therefore, genotypes with high GCA tend to produce good progeny vigor after being crossed (Olfati et al. 2012; Pandiarana et al. 2015; Ene et al. 2018; Murtadha et al. 2018; Zongo et al. 2019; Boyaci et al. 2020; Dianga et al. 2020; Datta et al. 2021). This means that the development of this variety can be directed into pure-line or composite varieties and the formation of hybrids (Bahari et al. 2012; Bouchetat and Aissat 2019, Marwiyah et al. 2019). Based on this study, the genotype with high GCA in almost all characters was the Mawar variety, followed by Chung. This indicates that crosses further employed for the breeding process should have one parent consisting of the Mawar or Chung varieties. The cross with the highest SCA on production and lycopene characters was F1 K/M and F1 M/C. Meanwhile, the cross with SCA, which was quite good in both traits, was the BC/K cross. The results indicated that K/M and M/C crosses are highly recommended for breeding in the next generation. This refers to the recommended parental GCA value in this study.

The BC/K crosses can also be recommended for breeding because they had a fairly good SCA in both parents, but the GCA value was considered poor for productivity and lycopene traits. In general, an F1 cross will undergo segregation in the F2 generation, producing the expected recombinant characters (Cazzola et al. 2020; Mackay et al. 2021) for the BC/K lineage to produce the expected offspring in both characters. K/M and M/C crosses will also have less chance of producing round or oval fruit offspring than BC/K crosses. However, the older species of Blackchery (BC) and Karina (K) had round and oval fruit shapes. Therefore, their offspring's chances of this kind of shape from this cross were high. Therefore, it was concluded that the BC/K cross can still be used in the lineage process.

Evaluation of double-cross compatibility between F1 half diallel

The results of double cross-compatibility were evaluated based on the female and male parents. This concept has also been reported by Bedinger et al. (2010), Zhang et al. (2019), and Farid et al. (2021) on crosses between tomato species, *Tagetes erecta* and *T. patula*, Farid et al. (2021) on crossing cocoa plants. The results of this study showed that F1 K/C became the best female parent in the double-cross, while F1 K/M and F1 BC/K were the best male parents. Based on the F1, Elder Karina became the basis for forming the best F1 for double-crossing. These results indicate that the use of Karina is excellent in terms of cross-compatibility. F1 K/M cross had good potential with SCA productivity during field evaluation, suggesting that it can increase the potential for productivity in the inheritance process. However, further support is required for the fruit phenotype of this cross. This evaluation can be performed by looking at the potential of GCA based on the character of the F1 K/M cross.

Table 3. Value of GCA and SCA of vegetative and inflorescence characters

Parent	PH	DF	DH	SD	NBP	NFB
GCA						
BC	-1.87	7.21^{k}	1.90^{k}	-0.72	-0.81^{l}	-1.33
C	2.98	-7.84^{n}	-2.01^{l}	-0.44	2.12^{k}	1.11
K	-2.28	2.19^{l}	2.03^{k}	0.56	-2.44^{m}	-0.33
M	1.17	-1.56^{m}	-1.92^{l}	0.6	1.12^{k}	0.55
SCA						
BC/C	-4.73	4.33^{b}	-1.14	0.20^{abcd}	1.63	0.35
BC/K	15.53^{abd}	7.46^{abc}	0.48	-0.06^{c}	2.63^{ad}	1.14^{ad}
BC/M	-1.48	-3.95	-1.01	-0.55	-0.26	0.7
K/M	-5.55	7.46^{abc}	1.73	0.23^{abcd}	-3.41	-1.42
K/C	-9.4	1.52^{c}	2.41	-0.03^{abcd}	-1.52	-1.19
M/C	13.23^{a}	7.66^{a}	0.34	-0.65^{d}	3.26^{a}	3.10^{a}
SE (GCA)	5.56	2.21	1.56	0.29	1.19	1.01
SE (Sii-Sij)	12.45	4.95	3.49	0.67	2.66	2.28
SE (Sii-Sjk)	11.13	4.43	3.12	0.6	2.38	2.04

Note: BC: Blackcherry, C: Chung, K: Karina, M: Mawar. For GCA, the numbers followed by the same letter in the row (k, l, m, n) are significantly different in the 5% least significant difference (LSD) test. For SCA, numbers followed by letters differ significantly from their parents, BC: a; C: b; K: c; M: d. PH: plant height PH, DF: days to flowering, DH: days to harvest, SD: stem diameter, NBP: number of bunches per plant, NFB: number of flowers per bunch

Table 4. Value of GCA and SCA of vegetative and fruit and yield characters

Parent	NFpB	FD	FL	TDS	FW	Yield	L
GCA							
BC	-0.18	-0.62^{m}	-0.87	1.18^{k}	-5.79	-5.55^{m}	2.28
C	0.67	-0.12^{l}	-0.29	-0.71^{l}	-2.75	-1.22^{l}	-0.25
K	-0.1	0.21^{l}	0.52	0.04^{k}	4.04	-2.11_{l}	-1.6
M	-0.39	0.54^{k}	0.64	-0.51^{l}	4.51	8.87^{k}	-0.43
SCA							
BC/C	0.05	0.95^{abcd}	0.08^{ad}	-0.16	-0.18	0.92^{abcd}	1.73^{bc}
BC/K	-0.87	-0.55^{c}	0.07^{ad}	0.33^{abc}	-1.77	0.85^{abcd}	5.03^{abcd}
BC/M	-1.22	-0.14	-0.53	-0.87	-2.4	-4.75	2.64
K/M	0.19	0.43^{a}	1.59^{abcd}	-0.28	13.29^{a}	4.40^{abcd}	-2.65
K/C	-0.64	-0.20^{d}	0.30^{abcd}	0.42^{abc}	-14.15	-9.87^{d}	-2.74
M/C	1.37^{a}	-0.67^{d}	-1.24^{d}	0.22^{bc}	-9.91	-3.84^{ad}	4.36^{abcd}
S.E (GCA)	0.4	0.36	0.26	0.2	0.74	0.45	0.87
SE (Sii-Sij)	0.9	0.81	0.6	0.46	1.66	1.02	1.95
S.E (Sii-Sjk)	0.8	0.72	0.53	0.41	1.49	0.92	1.75

Note: BC: Blackcherry, C: Chung, K: Karina, M: Mawar. For GCA, the numbers followed by the same letter in the row (k, l, m, n) are significantly different in the 5% LSD test. For SCA, numbers followed by letters differ significantly from their parents, BC: a, Cung: b, Karina: c, Mawar: d. NFpB: number of fruits per bunch, FD: fruit diameter, FL: fruit length, TDS: total dissolved solids, FW: fruit weight, L: lycopene

Table 5. The percentage value (%) of tomato crossing compatibility of the F1 hybrid double cross

ELDER F/M	BC/C	BC/K	BC/M	K/M	K/C	M/C	Female	Female (%)
BC/C	-	23.33	16.67	23.33	13.33	13.33	90.00	18.00
BC/K	20.00	-	16.67	26.67	16.67	26.67	106.67	21.33
BC/M	30.00	26.67	-	36.67	36.67	16.67	146.67	29.33
K/M	33.33	30.00	13.33	-	33.33	20.00	130.00	26.00
K/C	40.00	43.33	26.67	36.67	-	23.33	170.00	35.00
M/C	16.67	30.00	33.33	33.33	16.67	-	130.00	26.00
Male	140.00	153.33	106.67	156.67	116.67	100		
Male (%)	28	30.67	21.33	31.33	23.33	20		

Note: BC: Blackcherry, C: Chung, K: Karina, M: Rose; /: Cross single, F/M: female/male

Table 6. GCA value of fruit diameter (FD), fruit length (FL), fruit thickness (FT), fruit cavity (FC), total dissolved solids (TDS), fruit weight (FW), and the number of seeds (NS.)

Parent	FD	FL	FT.	FC	TDS	FW	NS
BC/C	-3.27^{e}	-2.80^{e}	-2.26^{e}	-0.22^{b}	0.53^{a}	-2.14^{c}	-0.36^{b}
BC/K	0.79^{b}	-0.40^{bcd}	0.99^{b}	0.12^{a}	0.34^{b}	-0.85^{b}	-2.03^{d}
BC/M	-0.31^{bcd}	-0.22^{bc}	-0.51^{c}	-0.01^{ab}	0.38^{b}	-0.95^{b}	1.14^{a}
K/C	3.75^{a}	6.37^{b}	3.38^{a}	-0.15^{ab}	-0.81^{d}	6.63^{a}	-1.90^{cd}
K/M	0.70^{b}	7.13^{a}	3.63^{a}	-0.38^{c}	-0.50^{c}	5.88^{a}	-3.13^{e}
M/C	-1.67^{de}	-3.26^{e}	-1.81^{cd}	0.10^{a}	-0.28^{b}	-2.53^{c}	-0.82^{c}

Note: BC: Blackcherry, C: Chung, K: Karina, M: Rose. The numbers followed by the same letter in the row (a, b, c, d, e) mean significantly different in the LSD test at 5% level

The results of the GCA evaluation showed that F1 K/C and F1 K/M had the best GCA values for all characters. This is in line with its potential compatibility as a parent of double-crossing. In general, this evaluation still involves the influence of the female parent. It was also found that the potential for fruit development of these crosses cannot be separated from the suitability of their male parents (Dung et al. 2021; Farid et al. 2021; Stasiak et al. 2021). As a result, crosses with F1 K/C and F1 K/M parents can increase the diversity of offspring in double-crosses and examples include K/C//BC/M, and BC/C//K/M. The K/C//K/M is an unbalanced three-way cross that is predicted to have high diversity. According to Vekariya et al. (2019), crosses with significant GCA values are expected to maximize opportunities for high genetic diversity in their offspring, specifically for the desired character. Therefore, double-crosses such as K/C//K/M, K/C//BC/M, and BC/C//K/M are expected to maximize the opportunities for diversity in F2 double cross progeny in terms of productivity and lycopene properties.

In conclusion, the tomato F1 half diallelic cross had high genetic diversity and good ability for almost all characters, specifically for total dissolved solids and yield. The non-additive gene action affected the lycopene, and its inheritance was based on the SCA analysis. The Mawar and Chung varieties were good and can be used as the parent for tomato crosses. Furthermore, K/M, M/C and BC/K were the best single F1 crosses to be passed on to the F2 generation. The F1 K/M and K/C crosses were the best male and female parents to use for double-crosses. The recommended double-crosses include K/C//BC/M, and BC/C//K/M, while for the F1 unbalanced three-way cross is K/C//K/M.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the scheme of Penelitian Dasar Unggulan Perguruan Tinggi (College Excellence Basic Research) with grant Number: 752/UN4.22/PT.01.03./2021.

REFERENCES

Acquaah G. 2012. Principles of plant genetics and breeding. 2nd Edition. Wiley-Blackwell, Oxford.

Afifah EN, Murti RH, Wahyudhi A. 2021. Evaluation of a promising tomato line (*Solanum lycopersicum*) derived from mutation breeding. Biodiversitas 22: 1863-1868. DOI: 10.13057/biodiv/d220432.

Amaefula C, Agbo CU, Nwofia GE. 2014. Hybrid vigour and genetic control of some quantitative traits of tomato (*Solanum lycopersicum* L.). J Genet 4: 30-39. DOI: 10.4236/ojgen.2014.41005.

Avdikos ID, Tagiakas R, Mylonas I, Xynias IN, Mavromatis AG. 2021. Assessment of tomato recombinant lines in conventional and organic farming systems for productivity and fruit quality traits. Agronomy 11: 129. DOI: 10.3390/agronomy11010129.

Ayenan MAT, Danquah A, Hanson P, Ampomah-Dwamena C, Sodedji FAK, Asante IK, Danquah EY. 2019. Accelerating breeding for heat tolerance in tomato (*Solanum lycopersicum* L.): An integrated approach. Agronomy 9: 720. DOI: 10.3390/agronomy9110720.

Bahari M, Rafil MY, Saleh GB, Latif MA. 2012. Combining ability analysis in complete diallel cross of watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai). Sci World J 2012: 543158. DOI: 10.1100/2012/543158.

Barreto FZ, Balsalobre TWA, Chapola RG, Garcia AAF, Souza AP, Hoffmann HP, Gazaffi R, Carneiro MS. 2021. Genetic variability, correlation among agronomic traits, and genetic progress in a sugarcane diversity panel. Agriculture 11: 533. DOI: 10.3390/agriculture11060533.
Bdr MF, Anshori MF, Emanuella G, Pratiwi N, Ermiyanti I, Yovita V, Musdalifa, Nasaruddin. 2020. High lycopene tomato breeding through diallel crossing. Agrotech J 5: 63-72. DOI: 10.31327/atj.v5i2.1347.
Bedinger PA, Chetelat RT, McClure B, Moyle LC, Rose JKC, Stack SM, Knaap E, Baek YS, Lopez-Casado G, Covey PA, Kumar A, Li W, Nunez R, Cruz-Garcia F, Royer S. 2010. Interspecific reproductive barriers in the tomato clade: Opportunities to decipher mechanisms of reproductive isolation. Sex Plant Rep 24: 171-187. DOI: 10.1007/s00497-010-0155-7.
Bouchetat F, Aissat A. 2019. Evaluation of the genetic determinism of an F1 generation of barley resulting from a complete diallel cross between autochthones and introduced cultivars Heliyon 5: e02744. DOI: 10.1016/j.heliyon.2019.e02744.
Boyaci HF, Prohens J, Unlu A, Gumrukcu E, Oten M. 2020. Association of heterotic groups with morphological relationships and general combining ability in eggplant. Agriculture 10: 203. DOI: 10.3390/agriculture10060203.
Breitel D, Brett P, Alseekh S, Fernie AR, Butelli E, Martin C. 2021. Metabolic engineering of tomato fruit enriched in L-DOPA. Metabolic Engineer 65: 185-196. DOI: 10.1016/j.ymben.2020.11.011.
Campanelli G, Sestili S, Acciarri N, Montemurro F, Palma D, Leteo F, Beretta M. 2019. Multi-parental advances generation inter-cross population, to develop organic tomato genotypes by participatory plant breeding. Agronomy 9: 119. DOI: 10.3390/agronomy9030119.
Campestrini LH, Melo PS, Peres LEP, Calhelha RC, Ferreira ICFR, Alencar SM. 2019. A new variety of purple tomato as a rich source of bioactive carotenoids and its potential health benefits. Heliyon 14: e02831. DOI: 10.1016/j.heliyon.2019.e02831.
Cappetta E, Andolfo G, Matteo AD, Barone A, Frusciante L, Ercolano MR. 2020. Accelerating tomato breeding by exploiting genomic selection approaches. Plants (Basel) 9: 1236. DOI: 10.3390/plants9091236.
Cazzola F, Bermejo CJ, Cointry E. 2020. Transgressive segregations in two pea F2 populations and their respective F2:3 families. Pesquisa Agropecuária Brasileira 55: e01623. DOI: 10.1590/s1678-3921.pab2020.v55.01623.
Chaudhary J, Alisha A, Bhatt V, Chandanshive J, Kumar N, Mir Z, Kumar A, Yadav SK, Shivaraj SM, Sonah H, Deshmukh R. 2019. Mutation breeding in tomato: Advances, applicability and challenges. Plants 8: 128. DOI: 10.3390/plants8050128.
Datta DR, Rafii MY, Misran A, Jusoh M, Yusuff O, Haque MA, Jatto MI. 2021. Half diallel analysis for biochemical and morphological traits in cultivated eggplants (*Solanum melongena* L.). Agronomy 11: 1769. DOI: 10.3390/agronomy11091769.
Deprá MS, Delaqua GCGD, Freitas L, Gaglianone MC. 2014. Pollination deficit in open-field tomato crops (*Solanum lycopersicum* L., solanaceae) in Rio de janeiro state, Southeast Brazil. J Pollination Ecol 12: 1-8. DOI: 10.26786/1920-7603(2014)7.
Dianga AI, Joseph KW, Musila RN. 2020. Analysis of combining ability for early maturity and yield in rice (Genus: *Oryza*) at the Kenyan Coast. Intl J Agron 2020: 6230784. DOI: 10.1155/2020/6230784.
Elbadrawy E, Sello A. 2016. Evaluation of nutritional value and antioxidant activity of tomato peel extracts. Arabian J Chem 9: S1010-S1018. DOI: 10.1016/j.arabjc.2011.11.011.
Ene CO, Ogbonna PE, Agbo CU, Chukwudi UP. 2018. Heterosis and combining ability in cucumber (*Cucumis sativus* L.). Inform Process Agric 6: 150-157. DOI: 10.1016/j.inpa.2018.07.008.
Ermiyanti I. 2021. Single Cross Evaluation of F1 Hybrids with Half Dialelic Analysis and Double Cross Compatibility in Tomatoes (*Solanum lycopersicum* L.). [Thesis]. Hasanuddin University, Makassar. [Indonesian]
Farid M, Nasaruddin, Anshori MF, Ridwan I, Israil S. 2021. Fruit trait-based evaluation of diallel crossing compatibility of six elite clones of cocoa. SABRAO J Breed Genet 53: 15-26.
Farooq MU, Ishaaq I, Maqbool R, Aslam I, Naqvi SMTA, Mustafa S. 2019. Heritability, genetic gain and detection of gene action in hexaploid wheat for yield and its related attributes. AIMS Agric Food 4: 56-72. DOI: 10.3934/agrfood.2019.1.56.
Fentik DA. 2017. Review on genetics and breeding of tomato (*Lycopersicon esculentum* Mill). Adv Crop Sci Tech 5: 306.
Fikere M, Barbulescu DM, Malmberg MM, Maharjan P, Salisbury PA, Kant S, Panozzo J, Norton S, Spangenberg GC, Cogan NOI, Daetwyler HD. 2020. Genomic prediction and genetic correlation of agronomic, blackleg disease, and seed quality traits in canola (*Brassica napus* L.). Plants. 9: 719. DOI: 10.3390/plants9060719.
Florido-Bacallao M, Lara-Rodríguez RM, Plana-Ramos D, Álvarez-Gil MA. 2021. Studies of gene action and heritability of the percentage of fruiting in tomato, cultivar Nagcarlang under conditions of heat stress. Cultivos Tropicales 42: e03.
Fraser GE, Jacobsen BK, Knutsen SF, Mashchak A, Lloren J. 2020. Tomato consumption and intake of lycopene as predictors of the incidence of prostate cancer: The adventist health study-2. Cancer Causes Control 31: 341-351. DOI: 10.1007/s10552-020-01279-z.
Ghareeb ZE, Fares WM. 2016. Modified model for assessment of maternal effectsin first generation of faba bean. Ann Agric Sci 61: 77-85. DOI: 10.1016/j.aoas.2016.01.004.
Hakim L, Suyamto. 2017. Gene action and heritability estimates of quantitative characters among lines derived from varietal crosses of soybean. Indonesian J Agric Sci 18: 25-32. DOI: 10.21082/ijas.v18n1.2017.p25-32.
Hivert V, Wray NR, Visscher PM. 2021. Gene action, genetic variation, and GWAS: A userfriendly web tool. PLoS Genet 17: e1009548. DOI: 10.1371/journal.pgen.1009548.
Holme IB, Gregersen PL, Brinch-Pedersen H. 2019. Induced genetic variation in crop plants by random or targeted mutagenesis: Convergence and differences. Front Plant Sci 10: 1468. DOI: 10.3389/fpls.2019.01468.
Joshi P, Gautam D. 2021. Genetic insights on single cross maize hybrid and its importance on maize self-sufficiency in Nepal. Archives Agric Environ Sci 6: 218-226. DOI: 10.26832/24566632.2021.0602014.
Kaur B, Sandhu KS, Kamal R, Kaur K, Singh J, Röder MS, Muqaddasi QH. 2021. Omics for the improvement of abiotic, biotic, and agronomic traits in major cereal crops: applications, challenges, and prospects. Plants 10: 1989. DOI: 10.3390/plants10101989.
Kaushik P, Dhaliwal MS. 2018. Diallel analysis for morphological and biochemical traits in tomato cultivated under the influence of tomato leaf curl virus. Agronomy 8: 153. DOI: 10.3390/agronomy8080153.
Kumar P, Paliwal A. 2016. Heterosis breeding for quality improvement in tomato (*Lycopersiconesculentum* Mill.) for cultivation in mid hills of Uttarakhand. Intl J New Technol Res 2: 75-78.
Kumar R, Srivastana K. 2021. Gene effects and heritability for yield traits in tomato (*Solanum lycopersicum* L.). Bangladesh J Bot 50: 453-465. DOI: 10.3329/bjb.v50i3.55823.
Leiva-Brondo M, Varcarcel M, Marti R, Roselio S, Cebolla-Cornejo J. 2016. New opportunities for developing tomato varieties with enhanced carotenoid content. Scientia Agricola 73: 512-519. DOI: 10.1590/0103-9016-2015-0427.
Mackay IJ, Cockram J, Howell P, Powell W. 2021. Understanding the classics: The unifying concepts of transgressive segregation, inbreeding depression and heterosis and their central relevance for crop breeding. Plant Biotechnol J 19: 26-34. DOI: 10.1111/pbi.13481.
Marwiyah S, Sutjahjo SH, Trikoesoemaningtyas, Wirnas D, Suwarno WB. 2021. High non-additive gene action controls synchronous maturity in mung bean. SABRAO J Breed Genet 52: 213-227.
Mat NHC, Bhuiyan MAR, Yaakob Z, Wickneswari R. 2020. Full diallel crosses in superior parents of *Jatropha curcas* L. Ind Crops Prod 151: 112482. DOI: 10.1016/j.indcrop.2020.112482.
Matos R, Resende JTV, Zeist AR, Corte LE, Da-Silva PR, Zeffa DM. 2021. Performance of the double-cross tomato hybrids from a partial diallel. Agric Sci 45: e027320. DOI: 10.1590/1413-7054202145027320.
Mawasid FP, Syukur M, Trikoesoemaningtyas. 2019. Epistatic gene control on the yield of tomato at medium elevation in the tropical agroecosystem. Biodiversitas 20: 1880-1886. DOI: 10.13057/biodiv/d200713.
Mistry C, Kathiria KB, Salobu S, Kumar S. 2016. Heritability and gene effects for yield related quantitative traits in eggplant. Ann Agric Sci 61: 237-246. DOI: 10.1016/j.aoas.2016.07.001.
Munene AK, Nzuve F, Ambuko J, Odeny D. 2018. Heritability analysis and phenotypic characterization of spider plant (*Cleome gynandra* L.) for yield. Adv Agric 2018: 8568424. DOI: 10.1155/2018/8568424.
Murtadha MA, Ariyo OJ, Alghamdi SS. 2018. Analysis of combining ability over environments in diallel crosses of maize (*Zea mays*). J Saudi Soc Agric Sci 17: 69-78. DOI: 10.1016/j.jssas.2016.01.004.
Mustafa M, Syukur M, Sutjahjo SH, Sobir. 2019. Inheritance study for fruit characters of tomato IPBT78 x IPBT73 using joint scaling test.

IOP Conf Ser Earth Environ Sci 382: 012009. DOI: 10.1088/1755-1315/382/1/012009.

Muthoni J, Shimelis H. 2020. Heat and drought stress and their implications on potato production under dry African tropics. Austr J Crop Sci14: 1405-1414. DOI: 10.21475/ajcs.20.14.09.p2402.

Nugraha Y, Ardie SW, Suwarno, Ghulamahdi M, Aswidinnoor H. 2016. Implication of gene action and heritability under stress and control conditions for selection iron toxicity tolerant in rice. AGRIVITA J Agric Sci 38: 282-295. DOI: 10.17503/agrivita.v38i3.740.

Ogunniyan DJ, Olakojo SA. 2015. Genetic variation, heritability, genetic advance and agronomic character association of yellow elite inbred lines of maize (*Zea mays* L.). Nigerian J Genet 28: 24-28. DOI: 10.1016/j.nigjg.2015.06.005.

Olfati JA, Samizadeh H, Rabiei B, Peyvast Gh. 2012. Griffing's methods comparison for general and specific combining ability in cucumber. 2012: 524873. DOI: 10.1100/2012/524873.

Oliveira JRF, Resende JTV, Filho RBDL, Roberto SR, Silva PR, Rech C, Nardi C. 2020. Tomato breeding for sustainable crop systems: High levels of zingiberene providing resistance to multiple arthropods. Horticulturae 6: 34. DOI: 10.3390/horticulturae6020034.

Pandiarana N, Chattopadhyay A, Seth T, Shende VD, Dutta S, Hazra P. 2015. Heterobeltiosis, potence ratio and genetic control of processing quality and disease severity traits in tomato. New Zealand J Crop Hortic Sci 43: 282-293. DOI: 10.1080/01140671.2015.1083039.

Parkes E, Aina O, Kingsley A, Iluebbey P, Bakare M, Agbona A, Akpotuzor P, Labuschagne M, Kulakow P. 2020. Combining ability and genetic components of yield characteristics, dry matter content, and total carotenoids in provitamin a cassava F1 cross-progeny. Agronomy 10: 1850. DOI: 10.3390/agronomy10121850.

Piosik Ł, Ruta-Piosik M, Zenkteler M, Zenkteler E. 2019. Development of interspecific hybrids between *Solanum lycopersicum* L. and *S. sisymbriifolium* Lam. via embryo calli. Euphytica 215: 31. DOI: 10.1007/s10681-019-2358-9.

Przybylska S. 2020. Lycopene – a bioactive carotenoid offering multiple health benefits: A review. Intl J Food Sci Technol 55: 11-32. DOI: 10.1111/ijfs.14260.

Raiola A, Tenore GC, Barone A, Frusciante L, Rigano MM. 2015. Vitamin E content and composition in tomato fruits: Beneficial roles and bio-fortification. Intl J Mol Sci 16: 29250-29264. DOI: 10.3390/ijms161226163.

Salava H, Thula S, Mohan V, Kumar R, Maghuly F. 2021. Application of genome editing in tomato breeding: Mechanisms, advances, and prospects. Intl J Mol Sci 22: 682. DOI: 10.3390/ijms22020682.

Schreinemachers P, Simmons EB, Wopereis MCS. 2018. Tapping the economic and nutritional power of vegetables. Global Food Security 16: 36-45. DOI: 10.1016/j.gfs.2017.09.005.

Singh RK, Chaudhary BD. 1979. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi.

Stasiak A, Latocha P, Bieniasz M. 2021. Effect of genetically diverse pollen on pollination, pollen tube overgrow, fruit set and morphology of kiwiberry (*Actinidia arguta*). Agronomy 11: 1814. DOI: 10.3390/agronomy11091814.

Statistic Indonesia. 2021. Produksi Tanaman Sayuran. https://www.bps.go.id/indicator/55/61/1/produksi-tanaman-sayuran.html. [Indonesian]

Suyadi, Rosfiansyah. 2017. The role of plant-parasitic nematodes on productivity reduction of banana and tomato in East Kalimantan, Indonesia. Asian J Agric 1: 40-45. DOI: 10.13057/asianjagric/g010108.

Syukur M, Sujiprihati S, Yunianti R, Undang. 2010. Diallel analysis using hayman method to study genetic parameters of yield components in pepper (*Capsicum annuum* L.). HAYATI J Biosci 17: 183-188. DOI: 10.4308/hjb.17.4.183.

Vekariya TA, Kulkarni GU, Vekaria DM, Dedaniya AP, Memon JT. 2019. Combining ability analysis for yield and its components in tomato (*Solanum lycopersicum* L.). Acta Sci Agric 3: 185-191. DOI: 10.31080/ASAG.2019.03.0541.

Vijeth S, Dhaliwal MS, Jindal SK, Garn N, Kaushik P, Sharma A. 2019. Diallel analysis of elite tomato lines comprising leaf curl virus resistance genes. Appl Ecol Environ Res 17: 6457-6471. DOI: 10.15666/aeer/1703_64576471.

Zeinab EG, Helal AG. 2014. Diallel analysis and separation of genetic variance components in eight faba bean genotypes. Ann Agri Sci 59: 147-154. DOI: 10.1016/j.aoas.2014.06.019.

Zhang H, Xin H, Cong R, Li Z, Song L, Wei Z. 2019. Cross compatibility analysis to identify suitable parents of *Tagetes erecta* and *T. patula* for heterotic hybrid breeding. Not Bot Horti Agrobo 47. DOI: 10.15835/nbha47311388.

Zongo A, Konate AK, Koïta K, Sawadogo M, Sankara P, Ntare BR, Desmae H. 2019. Diallel analysis of early leaf spot (*Cercospora arachidicola* Hori) disease resistance in groundnut. Agronomy 9: 15. DOI: 10.3390/agronomy9010015.

allel_of_F1_Tomato_Hybrid_and_its_Double_Cross-Compatibility.pdf

ORIGINALITY REPORT

15%	12%	9%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universitas Jenderal Soedirman Student Paper	1%
2	www.ambi-agua.net Internet Source	1%
3	usnsj.com Internet Source	1%
4	pubag.nal.usda.gov Internet Source	1%
5	www.frontiersin.org Internet Source	1%
6	dergipark.org.tr Internet Source	1%
7	researchspace.ukzn.ac.za Internet Source	<1%
8	horticulturejournal.usamv.ro Internet Source	<1%
9	academic.oup.com Internet Source	<1%

10	biodiversitas.mipa.uns.ac.id Internet Source	<1%
11	link.springer.com Internet Source	<1%
12	M Mustafa, M Syukur, S H Sutjahjo, Sobir. " Inheritance study for fruit characters of using joint scaling test ", IOP Conference Series: Earth and Environmental Science, 2019 Publication	<1%
13	Submitted to University of Sheffield Student Paper	<1%
14	Hasna Habib Sheikh, Abdul Latif Akanda Md, Hossain Kausar, Alam Ashraful. "Combining ability analysis in sunflower (Helianthus annuus L.) genotypes", Journal of Cereals and Oilseeds, 2021 Publication	<1%
15	krishikosh.egranth.ac.in Internet Source	<1%
16	Mehboob Alam, Muhammad Ayaz Khan, Muhammad Imtiaz, Muhammad Ali Khan et al. "Indol-3-Essigsäure sichert Pflanzenwachstum und Ertrag salzgestresster Tomaten (Lycopersicon esculentum L.)", Gesunde Pflanzen, 2019 Publication	<1%

17	repository.unhas.ac.id Internet Source	<1 %
18	L. Pelia, M. Riadi, Rafiuddin. "Growth response and yield of several local yam plants with hormax applications", IOP Conference Series: Earth and Environmental Science, 2020 Publication	<1 %
19	"Agricultural Biotechnology: Latest Research and Trends", Springer Science and Business Media LLC, 2021 Publication	<1 %
20	H. S. Hamisu, S. G. Ado, M. Y. Yeye, I. S. Usman et al. "Heterosis for Fruit Yield and Heat Tolerance Traits in Tomato (Lycopersicon Lycopersicum Mill.) Under Field Conditions", Journal of Agricultural Studies, 2018 Publication	<1 %
21	Zuyasna, E Hayati, Y Ghufrani, A Marliah, B Basyah, Nura. "Yield components of the M7 Kipas Putih mutant soybean", IOP Conference Series: Earth and Environmental Science, 2022 Publication	<1 %
22	www.aun.edu.eg Internet Source	<1 %
23	res.mdpi.com Internet Source	<1 %

24	Submitted to Universitas Hasanuddin Student Paper	<1%
25	apjtm.org Internet Source	<1%
26	www.biorxiv.org Internet Source	<1%
27	Mahdi Hassani, Bahram Heidari, Piergiorgio Stevanato. "Combining abilities of sugar beet genotypes for root‐ and sugar‐related traits under multi‐environment trials", Plant Breeding, 2019 Publication	<1%
28	www.hindawi.com Internet Source	<1%
29	actascientific.com Internet Source	<1%
30	aloki.hu Internet Source	<1%
31	"Floriculture and Ornamental Plants", Springer Science and Business Media LLC, 2022 Publication	<1%
32	"Nutraceuticals Production from Plant Cell Factory", Springer Science and Business Media LLC, 2022 Publication	<1%

33	Ilias D. Avdikos, Rafail Tagiakas, Pavlos Tsouvaltzis, Ioannis Mylonas, Ioannis N. Xynias, Athanasios G. Mavromatis. "Comparative Evaluation of Tomato Hybrids and Inbred Lines for Fruit Quality Traits", Agronomy, 2021 Publication	<1%
34	SR Ray, AKM Aminul Islam, MG Rasul, MMH Saikat, JU Ahmed. "Combining Ability for Yield Related Traits Of Boro Rice (Oryza Sativa L.)", Annals of Bangladesh Agriculture, 2022 Publication	<1%
35	jurnal.polinela.ac.id Internet Source	<1%
36	worldwidescience.org Internet Source	<1%
37	www.phytojournal.com Internet Source	<1%
38	"Accelerated Plant Breeding, Volume 4", Springer Science and Business Media LLC, 2022 Publication	<1%
39	A D Nasruddin, A Nurariaty, M Melina. " Effectiveness of nylon exclusion net for preventing chili fruit damage by the oriental fruit fly, Hendel (Diptera: Tephritidae) ", IOP	<1%

Conference Series: Earth and Environmental Science, 2020
Publication

---

40 Achmad Amzeri, Kaswan Badami, Amin Zuhri, Gita Pawana et al. "Assessment of Genetic Parameters for Vitamin A, Vitamin C, and TSS Content Results in Melon Line Crosses at Five Maturity Stages", International Journal of Agronomy, 2022 — <1%
Publication

---

41 Rafiul Amin Laskar, Samiullah Khan. "Assessment on induced genetic variability and divergence in the mutagenized lentil populations of microsperma and macrosperma cultivars developed using physical and chemical mutagenesis", PLOS ONE, 2017 — <1%
Publication

---

42 Rahul Chandel, A. T. Sadashiva, Kundapura V. Ravishankar, Anjan Das, Bichhinna Maitri Rout, Saurabh Singh. " Genetic combining, heterosis analysis for horticultural traits in tomato (L.) using ToLCV-resistant lines and molecular validation of genes ", Plant Genetic Resources: Characterization and Utilization, 2022 — <1%
Publication

---

43 ijtech.eng.ui.ac.id
Internet Source

<1 %

44	"Crop Breeding", Springer Science and Business Media LLC, 2021 Publication	<1 %
45	Che-Wei Chang, Yu-Hua Wang, Chih-Wei Tung. "Genome-Wide Single Nucleotide Polymorphism Discovery and the Construction of a High-Density Genetic Map for Melon (Cucumis melo L.) Using Genotyping-by-Sequencing", Frontiers in Plant Science, 2017 Publication	<1 %
46	Harnoor Kaur Dhillon, Sonia Sood, V. K. Sood, R. K. Chahota. "Hayman's diallel analysis to study genetic parameters of F1 generation of some bacterial wilt resistant intraspecific hybrids of bell pepper (Capsicum annuum L. var. grossum) under North Western Himalayan conditions of India", Vegetos, 2022 Publication	<1 %
47	Krishan K. Verma, Xiu-Peng Song, Garima Yadav, Hewan Demissie Degu et al. " Impact of Agroclimatic Variables on Proteogenomics in Sugar Cane (spp.) Plant Productivity ", ACS Omega, 2022 Publication	<1 %

48	bmcplantbiol.biomedcentral.com Internet Source	<1 %
49	docplayer.es Internet Source	<1 %
50	jhs.iihr.res.in Internet Source	<1 %
51	jurnal.ugm.ac.id Internet Source	<1 %
52	mdpi.com Internet Source	<1 %
53	techscience.com Internet Source	<1 %
54	www.omicsonline.org Internet Source	<1 %
55	www.plantarchives.org Internet Source	<1 %
56	www.scielo.br Internet Source	<1 %
57	Nasaruddin, S A Syaiful, BDR M Farid, I Ridwan, K Mantja, W Utami. " Effectiveness of soil tillage and Arbuscular Mycorrhizal (AM) fungi inoculation on fruit development of the cocoa plant (L.) ", IOP Conference Series: Earth and Environmental Science, 2020 Publication	<1 %

58	Swapan Chakrabarty, A. K. M. Aminul Islam, M. A. Khaleque Mian, Tofayel Ahamed. "Combining Ability and Heterosis for Yield and Related Traits in Chili (Capsicum annuum L.)", The Open Agriculture Journal, 2019 Publication	<1%
59	Divya Chaudhary, Swati, Kuldeep Nagar, Richa Dhyani. "Genetic Analysis of Yield and its Attributes in Bread Wheat (Triticum Aestivum L. Em. Thell) Under Irrigated and Rainfed Conditions", Research Square Platform LLC, 2021 Publication	<1%
60	P. Rethinam, V. Krishnakumar. "Coconut Water", Springer Science and Business Media LLC, 2022 Publication	<1%

Exclude quotes	On	Exclude matches	< 5 words
Exclude bibliography	On		