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High Lycopene Tomato Breeding Through Diallel Crossing

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Abstract

Tomatoes are known as one of the natural source of antioxidant, which is a compound that can inhibit and reduce oxidative cell and biomolecule damages, such as lipid, protein, and DNA. Health benefits from lycopene made this compound a tomato breeding subject for increasing its nutrient content. Tomato breeding is an environment friendly and sustainable method in agriculture biofortification methods, hence making the efforts for increasing tomato lycopene content to be possible. The aim of this research was to produce tomato hybrid with high lycopene and yield. This research was conducted in Experimental Farm, Faculty of Agriculture, Hasanuddin Univerisy, Makassar throughout June-Septermber 2020. This research was done in full diallel analysis using Griffing 1 method. Hybrid characters are highly determined with the presence of maternal effect. Lycopene has no correlation with productionCharacters correlated with lycopene are plant height, number of leaves, number of fruits per bunch, fruit length and fruit diameter, whilst productivity is correlated with number of leaves, stem diameter, and fruit diameter. Hybrids that can be used in further selection are CM, MC, MBC and KBC

Keywords: lycopne, full diallel, tomatoes, path analysis

A. Introduction

Tomato is one of widely cultivated horticulture commodity in Indonesia, both in high lands and low lands. Tomatoes are utilized in various products processing such as juice, sauces, salad, supplements, even beauty products. Indonesia was placed in 6th of world's tomato consumption by country, below Egypt (4,97%), India (5,87%), Turkey (6,83%), India (15,46%), and China (20,52%) (Pusdatin, 2018). The production of tomato for the last three years showed an upward trend from 962,845 ton ha^{-1} in 2017 to 976,772 ton ha^{-1} in 2018 dan 1,020,333 ton ha^{-1} in 2019 (BPS, 2020). Despite the fact, up to 9,411.578 tons of tomatoes were imported to Indonesia, both processed and fresh, valued $307,893 (Pusdatin, 2018).

Tomatoes are known as one of the natural source of antioxidant, which is a compound that can inhibit and reduce oxidative cell and biomolecule damages, such as lipid, protein, and DNA. The damage of human biomolecules is the primary source of aging as well as other serious diseases like cancer, respiratory diseases,cardiovascular, neurodegenerative and digestion systems (Liu, Ren, Zhang, Chuang, Kandaswamy, Zhou, & Zuo, 2018).

One of antioxidants found in tomatoes is lycopene. Lycopene ($C_{40}H_{56}$) is a phytochemical compound from synthesized carotenoid group from plants and microorganisms. Consumption of such compound is proven to be preventive in inhibiting cell damage caused by free radicals and minimizing risk of the emergence of various diseases such as cancer and heart attack as well as aging (Srivastava, 2017). Health benefits from lycopene made this compound a tomato breeding subject for increasing its nutrient content.

Lycopene availability in tomato fruits is identical with the color it produced. The more purple or darker the fruit, the higher lycopene content it possessed. This was mentioned by Park, Sangwanagkul, & Baek (2018), where purplish-brown tomatoes were discovered to have lycopene content of 185 mg kg^{-1} and higher than average red colored tomatoes. Besides dark colored tomatoes, high lycopene is known to be present in cherry and cocktail tomatoes (Passam, Karapanos, Bebeli, & Savvas, 2007). However, such tomato types are less common in farmers due to the smaller size. Despite the fact, the two types of tomatoes can be used as good parents in tomato breeding.

Tomatoes that are larger in size are the common cultivated tomatoes, being functioned as both fruit and vegetable. These tomato types have relatively low lycopene content. Increasing of lycopene content through cultivation aspects had been previously done, one of them was through agronomic supplementation or fertilizing. Taber, Veazie, Li, White, Rodermer & Xu (2008) discovered that potassium fertilizer doze were able to increase tomato lycopene content, yet had limited effects towards certain genotypes.

Tomato breeding is an environment friendly and sustainable method in agriculture biofortification methods, hence making the efforts for increasing tomato lycopene content to be possible. Diallel cross has proven in lycopene content increase from red and yellow colored tomatoes, where a number of high lycopene tomato parents were used as both male and female parents (Panthee, Veazie, Anderson, & Ibrahem, 2015).

Diallel cross is one of the basic plant breeding methods in launching new plant lines or varieties. This crossing method is considered to be effective in tomato breeding due to its controlled environment and its ability to produce high variability. Although requiring more manpower in order to do so, the mentioned method is easy, efficient, and has its own analysis that can show the occurred character inheritance (Souza, Meagz, Melo, & Melo, 2012). Panthee et al. (2015) in their research stated that the cross combination between 08133^{-1}(×)-7W, a yellow tomato genotype and black tomato *Chocolate Stripe* produced fruits with lycopene content of 62.5 mg g^{-1}. The lycopene content of high lycopene tomato parents used, *Chocolate Stripe* and 08133^{-1}(×)-7W were 74.9 5 mg g^{-1} and 13.0 mg g^{-1} respectively.

Diallel combination between high lycopene parents (Black Cherry and Chung) and low lycopene tomatoes was expected to produce tomatoes with high lycopene and yield. This breeding effort also supports government food security program as well as fulfilling one of the SDGS' goals in enhancing agricultural produce.

B. Methodology

This research was conducted in Experimental Farm, Faculty of Agriculture, Hasanuddin Univerisy, Makassar throughout June-Septermber 2020. This research was done in full diallel analysis using Griffing 1 method. The hybrids used were Chung x Black Cherry, Chung X Mawar, Chung x Karina, Karina x Chung, Karina x Black Cherry, Karina X Mawar, Mawar x Chung, Mawar x Karina, Mawar X Black Cherry, Black Cherry X Chung, Black Cherry x Karina, dan Black Cherry X Mawar and parents Chung F1, Karina, Mawar, and Black Cherry.

Path Analysis

Path analysis was calculated according to stimultan equation with formula as follows:

$$\underbrace{\begin{pmatrix} R_{11} & R_{12} & \dots & R_{1p} \\ R_{21} & R_{22} & \dots & R_{2p} \\ \dots & \dots & \dots & \dots \\ R_{p1} & R_{p2} & \dots & R_{pp} \end{pmatrix}}_{\mathbf{R_x}} \underbrace{\begin{pmatrix} C_1 \\ C_2 \\ \dots \\ C_p \end{pmatrix}}_{\mathbf{C}} = \underbrace{\begin{pmatrix} R_{1y} \\ R_{2y} \\ \dots \\ R_{py} \end{pmatrix}}_{\mathbf{Ry}}$$

Based on this equation, C value (direct effect) can be calculated with following formula

$$C = R_x^{-1} \times R_y$$

Note : Rx = Corelation matrix between free variable;

Rx^{-1} = Rx Inverse matrix

C = Path coefficient vector which indicated direct effect from each standarized free variable towards dependent variable.

Ry = Corelation coefficient vector towards Xi variable with dependent variable.

Lycopene Analysis

Lycopene was extracted using hexane:ethanol:acetone (2:1:1) (v/v) mixture following the method of Anthon and Diane, 2007; Adejo, Agbali & Otokpa, 2015 with some slight modifications. To analyse lycopene accumulated in fruit samples; the following five steps in analysis were followed:

1. Fresh fruit samples (0.001 g) were dissolved in 1ml of distilled water and vortexed in a water bath at 30˚C for 1 hour, then 8.0 ml of hexane : ethanol : acetone (2:1:1) added.
2. The samples were capped and vortexed immediately, then incubated out of bright light.
3. After at least 10 minutes, or as long as many hours later, 1.0 ml water was added to each sample and vortexed again.
4. Samples were allowed to stand for 10 minutes to allow phases to separate and all air bubbles to disappear, and finally absorbance of samples determined at 503 nm by spectrophotometry.
5. Calculation of the lycopene levels; lycopene levels in the hexane extracts were calculated according to Lycopene (mg/kg) = $Abs_{503nm} \times 537 \times 8 \times 0.55 / 0.10 \times 172$ or, $Abs_{503nm} \times 137.4$

Observed Parameters

The parameters observed were plant height (cm), number of leaves per plant, days of flowering (DAS/days after sowing), day of harvest (DAS), number of flowers per bunch, number of fruits per bunch, stem diameter (cm), fruit length (cm), fruit diameter (cm), brix (%), lycopene (mg g^{-1}), productivity (ton/ha).

C. Result and Discussion

Analysis of Variance and Genetic Components

Overall, P1, P2, interactions between P1 and P2, general combining ability (GCA) and specific combining ability (SCA) shows varied effect patterns. Female parent (P1) shows highly significance in almost every character except for brix. Male parent (P2) also indicates high significance towards days of flowering in nearly all characters except plant height, number of leaves per plant, day of harvest, and brix. Interaction between P1 and P2 shows high significance in almost all characters excluding fruit diameter and brix. GCA shows significance in days of flowering and harvest, stem diameter, fruit diameter, lycopene and production, whereas SCA indicates high significance in almost every character except for production.

Table 1. Analysis of variance and genetic components of plant height, number of leaves, days of flowering, day of harvest, number of flowers per bunch and number of fruits per bunch.

SoV	PH	NL	DoF	DoH	NfB	NFB
Replications	193.61	0.89	6.18	12.05*	0.21	0.14
P1	446.35**	74.52**	431.47**	365.25**	4.76**	7.57**
P2	131.37	10.17	218.96**	8.82	3.67**	12.75**
P1:P2	307.87**	19.36**	168.92**	65.61**	4.57**	5.78**
GCA	70.18	18.22	201.63 *	71.73*	0.77	6.50 *
SCA	139.90 **	7.91 **	76.17 **	24.91 **	1.90**	1.80 **
Resiprocal	75.25 **	6.78 **	15.90 **	34.40 **	1.4262 **	1.25 **
Error	21.56	1.34	1.28	1.17	0.26	0.34
Additive variance	0.00	2.70	32.81	12.20	0.00	1.19
Dominant variance	72.81	4.04	46.10	14.60	1.00	0.90
h2 bs (%)	0.00	0.33	0.41	0.43	0.00	0.50
h2 ns (%)	0.77	0.83	0.98	0.96	0.79	0.86

Note: "*" = 95% significance, ""=99% significance PH= plant height, NL = number of leaves, DoF = Days of flowering, DoH = Day of harvest, NfB = number of flowers per bunch, NFB = Number of fruits per bunch**

According to ANOVA (Table 1 and Table 2), maternal effect has high significance towards tomato characters. The ANOVA table used in diallel analysis to know the significance of existed genetic components (Hayman, 1954). GCA is means of genotype performance in hybrid combination, whereas SCA is hybrid combination with better means than the respective parents (Fasahat, Rajabi, Rad, & Derera, 2016).

It can be seen from the ANOVA table that reciprocal effect was found to be significant. This is caused by the presence of maternal effect which determine the F1 phenotype. This statement is similar to research done by Ghareeb & Fares (2016) in faba bean that reciprocal effect can influence hybrid expression in first generation caused by genetic and sitoplasmic function, thus choice of parents is crucial. Mustafa, Syukur, Sutjahjo, & Sobir (2019), showed that the characters of yield component (fruit length, fruit diameter, fruit size, weight per fruit, fruits number per plant) were controlled by many genes and and there were no maternal effects.

Regarding two main characters in this research, lycopene and productivity, there were significant reciprocal effect in both characters. The similar was also discovered by Aisyah, Wahyuni, Syukur, & Witono (2016) that additive gene action was present in productivity. Not only that, Kumar, Reddy, Reddy, Pandavada, & Saidaiah (2016) also noted that lycopene inheritance is caused by additive gene influence.

Table 2. Analysis of variance and genetic components of stem diameter, fruit length, fruit diameter, brix, lycopene, and productivity

SoV	SD	FL	FD	Brix	L	P
Replications	0.26	0.24	0.11	0.03	18.66	9377252.00**
P1	4.99**	5.03**	2.96**	9.31	245.20**	37305272.00**
P2	6.58**	2.52**	2.52**	4.51	86.31**	11349616.00**
P1 : P2	2.12**	2.31**	1.17	2.49	138.61**	2686370.00
GCA	2.41 *	2.33	1.74 *	3.77 **	100.94	13026299 **
SCA	0.81 **	1.10 **	0.50*	0.60 **	42.62**	1101509.00
Resiprocal	1.00 **	0.15	0.13	1.08 **	31.469 **	1837674 **
Error	0.11	0.16	0.18	0.02	5.39	493217.30
Additive variance	0.41	0.32	0.32	0.81	15.30	2992895.40
Dominant variance	0.43	0.58	0.20	0.35	23.00	374333.46
h2 bs (%)	0.43	0.31	0.46	0.69	0.35	0.78
h2 ns (%)	0.88	0.85	0.75	0.98	0.88	0.87

Note: "*" = 95% significance, ""=99% significance SD= stem diameter, FL= fruit length, FD = Fruit diameter, L = Lycopene, P= productivity**

General and Specific Combining Ability

Highest GCA from plant height is given by Mawar, although not significantly different compared to BC and C. Mawar also displayed the highest GCA for number of leaves per and not significantly different towards C, while the lowest SCA from the character was given by K. The lowest GCA of days of flowering is shown by C, whilst K presented the highest of the character. The similar is also shown in days of harvest. BC presented the highest GCA for number of flowers per bunch and is not significantly different than C and K, whilst the lowest GCA was derived from M. BC also presented highest GCA in number of fruits per bunch and is not significantly different from C, while K presented the lowest value (Table 3).

Highest GCA value from stem diameter was found in M, whereas the lowest was present in BC. K displayed the highest fruit length GCA value while BC presented the lowest and is not significantly different from C. BC displays highest brix GCA value whereas C presented as the lowest. M has a good combining ability to obtain high lycopene GCA value and is not significantly different from BC, whereas K presented lowest value. M also presented highest GCA value for productivity and K as the lowest.

Table 3. General combining ability of plant height, number of leaves, days of flowering, day of harvest, number of flowers per bunch and number of fruits per bunch.

No.	Parent	PH	NL	DoF	DoH	NfB	NFB
1	BC	0.20 ab	-0.4 b	5.15 a	1.94 a	0.28 a	1.00 a
2	C	1.60 a	1.09 a	-6.55 d	-3.83 c	0.02 ab	0.41 a
3	K	-4.24 b	-1.97 c	2.30 b	2.77 a	0.14 a	-1.07 c
4	M	2.40 a	1.27 a	-0.90 c	-0.88 b	-0.44 b	-0.34 b
S.E (GCA)		4.74	1.18	1.16	1.11	0.52	0.60

Note : BC = Black Cherry, C = Chung, K = Karina, M = Mawar
PH= plant height, NL = number of leaves, DoF = Days of flowering, DoH = Day of harvest, NfB = number of flowers per bunch, NFB = Number of fruits per bunch

Table 4. General combining ability of stem diameter, fruit length, fruit diameter, brix, lycopene, and productivity

No.	Parent	SD	FL	FD	Brix	L	P
1	BC	-0.66 c	-0.45c	-0.51 b	0.87 a	2.00 a	-1211.78 c
2	C	0.00 b	0.16 b	-0.28 b	-0.76 d	-0.63 b	-309.95 b
3	K	-0.02 b	0.69 a	0.46 a	0.13 b	-4.72 c	-278.98 b
4	M	0.67 a	-0.41c	0.32 a	-0.24 c	3.34 a	1800.71 a
S.E (GCA)		0.34	0.41	0.43	0.16	2.37	717.14

Note: BC = Black Cherry, C = Chung, K = Karina, M = Mawar
SD= stem diameter, FL= fruit length, FD = Fruit diameter, L = Lycopene, P= productivity

SCA analysis shows that BCK hybrid has highest SCA value in plant height compared to BC and K. Only four hybrids present good SCA value in number of leaves and is significant towards BC and K. Highest SCA value in days of flowering was shown in CM, significantly different than BC, C, K and M, whilst lowest SCA value is found in BCM. Almost all hybrids presented good SCA value in days of harvest compared to C and M, where the lowest is found in KC hybrid and highest found in CBC. Three hybrids presented favorable SCA value in number of flowers per bunch compared to K and M. SCA value for number of fruits per bunch presented that BCK, BCB, CK, CM, and KM for having better values compared to K and M (Table 5).

There were differences found in the effects between GCA and SCA, where characters in ANOVA table shown insignificant GCA value yet having highly significance in SCA and vice versa. This condition is supported by Fasahat et al. (2016) regarding GCA and SCA interactions, that such condition can be caused by the parents and non-additive gene interaction was present, such as dominance and epistatis.

According to GCA analysis, it was found that M has good combining ability for lycopene and production. Not only that, M also possesses good combining ability in other parameters such as plant height, number of leaves, days of flowering, day of harvest, and stem diameter. BC is shown to have highest GCA on brix, but not production. The similar phenomenon was found by Vekariya, Patel, Modha & Mali (2019) related to tomato biochemical components and production GCA values.

SCA was estimated in order to find the combining ability of respective parents to produce hybrid with characters better than the parents. Hybrid with the best SCA for lycopene conent was found in CM. Not only that, CM also gave good combining ability for almost every parameters except fruit length, diameter, and production. CK possesses highest SCA for production, but presented significant SCA for days of flowering, days of harvest, number of fruits per plant and brix. KBC presented good SCA value for both lycopene and production which is significant towards B, C, and K. This condition is supported by Vekariya et al. (2019), stating that crosses with significant SCA shows that at least one of the parents has good SCA value and is expected to maximize the favored character.

Table 5. Specific combining ability of plant height, number of leaves, days of flowering, day of harvest, number of flowers per bunch and number of fruits per bunch.

No.	Hybrid	PH	NL	DoF	DoH	NfB	NFB
1	BCC	-3.69	-1.74	-0.39 b	-5.68	-0.83	-1.18
2	BCK	10.86 ac	2.75 ac	3.07 b	4.41 b	-0.66	0.42 c
3	BCM	5.28	-1.42	-3.32 b	-0.34 b	-0.400	-0.49
4	CBC	-5.00	1.22 c	5.06 bcd	7.72 acd	1.06 cd	1.10 cd
5	CK	-3.61	-1.73	4.85 bcd	-1.12 b	0.25	0.37 c
6	CM	9.25 ac	2.59 ac	8.27 abcd	2.31 bd	1.10 cd	1.42 cd
7	KBC	0.73	-0.68	2.38 b	2.04 bd	-1.10 cd	-1.23
8	KC	1.83	2.00 ac	-0.44 b	-5.67 b	-1.07	0.43 c
9	KM	-7.64	-0.13	-0.80 b	-0.56 b	-0.72	-0.200
10	MBC	-13.33	-1.72	0.34 b	0.33 b	-0.59	-0.52
11	MC	-0.89	-1.56	3.89 bd	0.56 b	0.17	0.17 c
12	MK	-4.28	-3.00 d	1.00 b	2.61 b	0.65	-0.74
S.E (Sii - Sij)		10.60	2.64	2.59	2.47	1.16	1.33
S.E (Sii - Sjk)		8.21	2.04	2.00	1.91	0.9	1.03

Note : BC = Black Cherry, C = Chung, K = Karina, M = Mawar
PH= plant height, NL = number of leaves, DoF = Days of flowering, DoH = Day of harvest, NfB = number of flowers per bunch, NFB = Number of fruits per bunch

Tabel 6. Specific combining ability of stem diameter, fruit length, fruit diameter, brix, lycopene, and productivity

No.	Hybrid	SD	FL	FD	Brix	L	P
1	BCC	**0.54 a**	**0.51 ad**	**0.73 b**	-0.86	-2.43	-67.5
2	BCK	**0.73 abc**	-0.17	-0.15	**-0.28 b**	4.13	9.6
3	BCM	-0.11	0.12	-0.37	**0.05 b**	2.34	-450.3
4	CBC	**1.37 abcd**	0.24	0.45	**1.16 bcd**	-0.80	**427.09 a**
5	CK	0.09	**1.10 abd**	0.12	**0.44 bd**	-2.30	**615.84 a**
6	CM	**0.30 a**	-0.57	-0.51	**0.11 b**	**5.58 bc**	-541.3
7	KBC	-0.61	-0.06	-0.09	**0.94 bcd**	**4.74 bc**	**165.20 a**
8	KC	**-0.64 c**	-0.06	0.02	**0.65 bcd**	-3.25	-1174.9
9	KM	-0.56	**0.30 a**	-0.05	**0.14 b**	**1.64 c**	-809.9
10	MBC	**0.18 a**	0.07	-0.13	-0.76	**-3.09a**	-416.9
11	MC	-0.5	0.00	0.02	**-0.02 b**	**5.18 c**	-1410.2
12	MK	-0.06	0.62	0.39	**0.05 b**	-4.93	-1326.8
S.E (Sii - Sij)		0.76	0.92	0.96	0.35	5.3	1603.6
S.E (Sii - Sjk)		0.59	0.71	0.74	0.27	4.1	1242.12

Note: BC = Black Cherry, C = Chung, K = Karina, M = Mawar
SD= stem diameter, FL= fruit length, FD = Fruit diameter, L = Lycopene, P= productivity

SCA for fruit diameter indicates that CBC, BCK, BCC, MBC and KC have best SCA values compared to BC and K. Only three hybrids presented best SCA in fruit length: BCC, CK, and KM compared to B, C,and M. BCC presents best SCA value in fruit diameter and significantly different than C. SCA for brix indicates that nearly all varieties displays good SCA value compared to C. CM presents the highest lycopene SCA value and the lowest from MBC. CBC, CM and KBC have best SCA value in production compared to BC.

Cross combination with high SCA can be considered as precursor for hybrid variety creation. It is highly possible that best hybrid can be produced from the cross of two cultivars with high GCA value, but crosses between two parents with least GCA value can also produce good SCA (Iriany, Sujiprihati, Syukur, Koswara, & Yunus, 2011). However, the significance of SCA towards a character alone cannot be used as sole basis for plant breeding because of the possibility of producing less means compared to the original parent, thus heterosis and heterobeltiosis analysis is needed.

Heterosis and Heterobeltiosis

Heterosis and heterobeltiosis calculation is shown in table 5 and 6. Overall, not all hybrid combinations presented significance in every character. Highest heterosis value in stem diameter is shown in BCC and lowest in BCM . CM presents highest heterosis in fruit length, while the lowest is given by KM. MK gives highest positive heterosis in brix and lycopene, whilst the lowest was derived from MBC.

BCC presents best heterobeltiosis value for stem diameter. CK gives highest heterobeltiosis for fruit length, whereas the lowest was given by KC. Highest heterobeltiosis value for brix is found in MBC while the lowest is found in KM. Significant positive heterosis value is found highest in BCM and the lowest by MK.

Heterosis and heterobeltiosis is conducted to obtain better hybrid performance from either a parent or both parents (Marame, Dessalegne, Fininsa & Sigvald, 2009; Wiguna & Sumpena, 2016). Heterosis result shows that there are significance towards almost every character. Yet, no significance was found in productivity, both in heterosis and heterobeltiosis.

Heterosis is a superiority of hybrid performance or a cross from the value of both parents, whereas the superiority of hybrids better than the parents is called heterobeltiosis (Syukur, Sujiprihati, & Yunianti, 2015). Positive heterosis indicates that the cross of both parents will produce hybrid with higher characters from the parents on certain extent. The utilization of heterosis is a faster method to combine characters used as basis for further selection and determining higher significance in hybrid production. Heterosis estimation helps in desirable hybrid production economically.

Hybrid with best heterosis in lycopene is MK. This signifies the presence of hybrid vigor in the character. Significant positive heterosis shows that there is an additive gene in lycopene inheritance. However, no significance is found in SCA table for the hybrid. If a character's significance is shown both in SCA and heterosis, the hybrid can be used for further selection. MBC has lowest significant positive heterosis in lycopene and is supported by negative SCA. Furthermore, if SCA is negative, there is a tendency for positive dominance to take place, thus increasing heterosis.

Significant heterobeltiosis is shown in CM, yet no significance in heterosis and SCA is found. This shows that hybrid performance with better parent in the character. Similar condition was discovered by Rasheed, Ahmed, Wassan, Salongi, Aamer, Khansada, Keerio, Qadeer, & Ahmed (2018) regarding hybrid vigor in tomatoes. Meanwhile, BCK did not have significance in lycopene heterobeltiosis although shown positive significant value in heterosis. Non-significant value of heterobeltiosis in most combination can be caused by loss of heterosis components.

Correlation analysis

Correlation analysis result is shown in table 9. According to table 9, lycopene as primary character is not correlated with lycopene, another crucial character. Hence, the focus of the analysis is divided into two parts. Based on the lycopene correlation analysis result in table 10, plant height (0.44), number of leaves (0.45) , number of fruits per bunch (0.42), fruit length (-0.56) and fruit diameter (0.69) shows correlation towards lycopene. Meanwhile, there are three characters with correlation towards productivity: number of leaves (0.3), fruit length (0.58), and fruit diameter (0.33).

Correlation analysis was used to depict the level of linear relationship of two or more changers. The strength of the relationship between two characters with value close to 1 and -1. Character correlation indicates relationship towards various characters and determine selection characters in for increased production and productivity supporting characters.

The absence of correlation between lycopene and production caused the further analysis done separately. Same discovery was found from Zörb, Piepho, Zikeli, & Horneburq (2020), that lycopene in tomatoes is not correlated with with fresh fruit weight as production supporting character. Correlation analysis towards lycopene shows that there are five supporting characters with significance: plant height, number of leaves, number of fruits per bunch, fruit length, and fruit diameter. It is found that in correlation analysis for production, three characters was found having correlation: number of leaves, stem diameter and fruit diameter. The plants with more leaves have more chance to utilize energy from photosynthesis and produce photosyntates.

Table 9. Correlation analysis towards lycopene

No	1	2	3	4	5	6	7	8	9	10	11	12
1	**1.00**											
2	0.50 tn	**1.00**										
3	-0.03 tn	-0.16 tn	**1.00**									
4	-0.17 tn	-0.14 tn	0.57 tn	**1.00**								
5	-0.10 tn	-0.02 tn	0.21 tn	0.31 tn	**1.00**							
6	0.19 tn	0.46 tn	0.21 tn	0.06 tn	0.56 tn	**1.00**						
7	0.14 tn	0.24 tn	0.00 tn	0.07 tn	-0.05 tn	-0.13 tn	**1.00**					
8	-0.23 tn	-0.48 tn	0.09 tn	-0.02 tn	-0.16 tn	-0.44 tn	0.14 tn	**1.00**				
9	-0.14 tn	-0.29 tn	0.00 tn	0.00 tn	-0.24 tn	-0.63 tn	0.42 tn	0.64 tn	**1.00**			
10	-0.08 tn	-0.09 tn	0.63 tn	0.58 tn	0.23 tn	0.28 tn	-0.35 tn	-0.13 tn	-0.17 tn	**1.00**		
11	**0.44***	**0.49***	0.17 tn	0.08 tn	-0.05 tn	**0.42***	0.03 tn	**-0.56***	**-0.49***	0.09 tn	**1.00**	
12	-0.02 tn	0.30 tn	-0.19 tn	-0.06 tn	-0.09 tn	-0.14 tn	0.58 tn	-0.08 tn	0.33 tn	-0.21 tn	0.10 tn	**1.00**

Note: (*) = significant, (**) = highly significant, tn = not significant

Table 10. Correlation analysis towards productivity

No	1	2	3	4	5	6	7	8	9	10	11	12
1	**1.00**											
2	0.50 tn	**1.00**										
3	-0.03 tn	-0.16 tn	**1.00**									
4	-0.17 tn	-0.14 tn	0.57 tn	**1.00**								
5	-0.10 tn	-0.02 tn	0.21 tn	0.31 tn	**1.00**							
6	0.19 tn	0.46 tn	0.21 tn	0.06 tn	0.56 tn	**1.00**						
7	0.14 tn	0.24 tn	0.00 tn	0.07 tn	-0.05 tn	-0.13 tn	**1.00**					
8	-0.23 tn	-0.48 tn	0.09 tn	-0.02 tn	-0.16 tn	-0.44 tn	0.14 tn	**1.00**				
9	-0.14 tn	-0.29 tn	0.00 tn	0.00 tn	-0.24 tn	-0.63 tn	0.42 tn	0.64 tn	**1.00**			
10	-0.08 tn	-0.09 tn	0.63 tn	0.58 tn	0.23 tn	0.28 tn	-0.35 tn	-0.13 tn	-0.17 tn	**1.00**		
11	0.44 tn	0.49 tn	0.17 tn	0.08 tn	-0.05 tn	0.42 tn	0.03 tn	-0.56 tn	-0.49 tn	0.09 tn	**1.00**	
12	-0.02 tn	**0.30***	-0.19 tn	-0.06 tn	-0.09 tn	-0.14 tn	**0.58***	-0.08 tn	**0.33***	-0.21 tn	0.10 tn	**1.00**

Note: (*) = significant, (**) = highly significant, tn = not significant

1. **Plant height**
2. **Number of leaves per plant**
3. **Days of flowering**
4. **Day of harvest**
5. **Number of flowers per bunch**
6. **Number of fruits per bunch**
7. **Stem diameter**
8. **Fruit length**
9. **fruit diameter**
10. **Brix**
11. **Lycopene**
12. **Productivity**

Path Analysis

According to lycopene path analysis on table 11, plant height and number of leaves shows direct positive effect and number of fruits per bunch, fruit length and diameter shows negative direct effect. Based on table 12 about production path analysis, number of leaves, stem diameter and fruit diameter shows direct positive effect.

Table 11. Direct and indirect effects of some characters towards lycopene

Character	Direct Effect	Indirect Effect					Total Effect
		PH	NL	NFP	FL	FD	
PH	0.27		0.25	-0.10	0.08	0.00	0.50
NL	0.50	0.13		-0.25	0.16	0.01	0.56
NFB	-0.53	0.05	0.23		0.15	0.02	-0.09
FL	-0.34	-0.06	-0.24	0.23		-0.02	-0.42
FD	-0.03	-0.04	-0.14	0.34	-0.22		-0.09
Remaining Effect	-0.13						

Note: PH = plant height, NL = number of leaves, NFP = number of fruits per bunch, FL = fruit length, FD = fruit diameter

Table 12. Direct and indirect effects of some characters towards productivity

Character	Direct Effect	Indirect Effect			Total Effect
		Number of Leaves	Stem Diameter	Fruit Diameter	
Number of Leaves	0.27		0.10	-0.07	0.30
Stem Diameter	0.42	0.06		0.10	0.58
Fruit Diameter	0.23	-0.08	0.17		0.33
Pengaruh	0.92				

Association degree in characters from correlation analysis can be used as a ground in breeding character selection. Tomato productivity is an end product influenced by other complex characters. Path analysis becomes crucial to find out the effects of a supporting character towards the selected main character. Path coefficient analysis results in effective means in order to know the direct and indirect effects of supporting character towards main characters.

Path analysis for lycopene shows that the highest direct effect was presented by number of leaves, 0.50 and its indirect effect, 0.25. Path analysis for production shows highest direct effect value from stem diameter, 0.42 and indirect effect of 0.17. Mustafa *et al.* (2018), show that the characters with great direct effect on weight per plant were number of fruits per plant and weight per fruit with direct effect of 0.532 and 0.456, respectively.

D. Conclusion

Based on this research, it can be concluded that:

1. Hybrid characters are highly determined with the presence of maternal effect
2. Lycopene has no correlation with production
3. Characters correlated with lycopene are plant height, number of leaves, number of fruits per bunch, fruit length and fruit diameter, whilst productivity is correlated with number of leaves, stem diameter, and fruit diameter.
4. Hybrids that can be used in further selection are CM, MC, MBC and KBC

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