Utilization of local cayenne pure lines for F-1 hybrid breeding program

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Abstract. Local cayenne can be used as a good genetic material for F-1 hybrid variety. The purpose of this research was to analyze and estimate general (GCA) and specific combining ability (SCA), heterosis, and heterobeltiosis value, then to evaluate and select F-1 progenies. The research was conducted from February to December 2019 at Indonesian Vegetables Research Institute, Lembang, (1,250 m sal). The genetic material consisted of six local cayenne lines i.e.: BNT, GNY, SGT, BGJ, HIU, MDN, 15 F-1 progenies, and STK as a commercial variety. The results showed that: (1) BGJ line had the highest GCA value on weight per one fruit (0.74), fruit length (0.77), fruit diameter (0.57), and fruit weight per plant (13.83), while the highest GCA value on fruit number per plant was MDN line (35.69); (2) F-1 SGT x HIU had the highest SCA value on weight per one fruit (0.27), fruit length (0.56), and fruit weight per plant (69.90), while the highest SCA values fruit diameter (0.48) and fruit number per plant (129.29) were obtained by F1 HIU x MDN and F-1 BGJ x HIU respectively; (3) F-1 BNT x MDN, F-1 SGT x HIU, F-1 BGJ x MDN are recommended as advance hybrid lines.

1. Introduction.
Cayenne is one chili type that consumed widely in Indonesia [1]. Cayenne demand always increase for consumption and raw material of medicinal and cosmetic due to capsaicin and vitamin C content [2]. In addition, cayenne has a high yield potential because they can grow for a year [3]. Cayenne production had tended to increase from 1980 to 2018 along with increasing harvested area. However, their availability fluctuated due to irregular harvest times in every year. This fluctuation caused selling domestic market price to become unstable and made micro inflation in Indonesia [4-5].

Cayenne production fluctuation is caused by various growing seasons and environmental factors. All this time, open pollinated (OP) variety of cayenne was cultivated to fulfill availability supply. However cayenne OP variety is less able to maintain their yield potential genetically because high enough cross pollination naturally, moreover if the seed production process neglected isolation factors in the field [6]. F-1 hybrid variety are one of solutions to ensure cayenne genetic purity. Furthermore existence phenomenon of heterosis or heterobeltiosis in F-1 hybrid will have an impact on increasing yield up to 61% higher than OP variety [7-8]. Heterosis or hybrid vigor is a phenomenon where hybrid progeny has superior performance compared to their parental inbred lines [9]. But if the hybrid progeny has performance over the best their parent, so the phenomenon is known as heterobeltiosis [10-12].

Indonesian Vegetable Research Institute (IVEGRI) has a local cayenne germplasm collections. These collections can be utilized as a genetic material for F-1 hybrid variety. Local cayenne had adapted well in surrounding environment, therefore usually it has a good tolerance for biotic or abiotic
stress [13]. The activity of crossing hybridization between local cayenne pure lines, either in full or half diallel, needs to be done to determine F-1 hybrid parent candidates [14].

The purpose of this research was (1) to analyze and estimate general (GCA) and specific combining ability (SCA) heterosis, and heterobeltiosis value of F-1 progenies; (2) to evaluate and select F-1 hybrid candidate as a new variety.

2. Material and Method
The research was conducted from February to December 2019 at IP2TP Margahayu, IVEGRI-Lembang (1,250 m asl). The research used randomized complete block design (RCBD) with three replications. The genetic material consisted of six cayenne pure lines i.e.: BNT, GNY, SGT, BGJ, HIU, MDN, 15 F-1 progenies, and STK as a reference commercial variety. The experimental field was covered by silver plastic mulch with a spacing of 70 x 50 cm and a population number of 15 plants/genotype/replication.

Cultivation technique included application of dolomite lime (1.5 t ha\(^{-1}\)) and basic fertilization consisting of horse manure (20 t ha\(^{-1}\)) and NPK hydrocomplex (100 g per m\(^2\)), applied a week before planting. Subsequent NPK fertilization was applied when the plants age 30, 45, 60, and 75 days after planting (DAP) given by dilution it into the planting hole (dose 1500 g per 100 l). Plant maintenance included watering, weeding, and pest-disease protection by pesticides. Harvesting was done for 8 times once a week.

The observation parameters consisted of weight per fruit, fruit length, fruit diameter, fruit weight per plant and number of fruits per plant. General (GCA) and specific combining ability (SCA) were analyzed using the Griffing II method based on half diallel. There is an assumption that no reciprocal effect in this case. Heterosis estimation was calculated by mid-parent heterosis (MP) which F-1 hybrid vigor compared with mid parents performance, whereas heterobeltiosis was calculated by high-parent heterosis (HP) which F-1 hybrid vigor compared with the best parent performance [10, 15-16].

Heterosis and heterobeltiosis formula [17]:

\[
\text{Heterosis mid parent} = \frac{F1 - (P1 + P2) / 2}{(P1 + P2) / 2} \times 100\%
\]

\[
\text{Heterobeltiosis} = \frac{F1 - \text{the best parent}}{\text{the best parent}} \times 100\%
\]

F test was performed to determine genotype effect on observed parameter variance. If the parameter had a significant effect between F-1 hybrid genotypes, so it would be carried out Duncan's Multiple Range Test (DMRT) at 5% level as a subsequent test to determine the best F-1 hybrid. It was carried out also by the Dunnett test at 5% level to evaluate yield parameters performance of each F-1 hybrid genotypes compared with STK as a reference commercial variety [18-19].

3. Result and Discussion

3.1. General (GCA) and specific combining ability (SCA) of six local cayenne pure lines
The variance analysis showed that the evaluated genotypes had a significant effect on all the observed parameters, so that the variance analysis for combining ability could be carried out (Table 1). The general combining ability (GCA) showed a significant effect on parameter of weight per fruit, fruit length, and fruit diameter, while the specific combining ability (SCA) had a significant effect on parameter of fruit length, number of fruits per plant and fruit weight per plant. Hafsah et al. [20] stated that the GCA and SCA significant value indicated existence of additive and dominant genes in the observed parameter.
Table 1. The variance analysis of crossing between six local cayenne pure lines by half diallel

| Variability | Source | Degree of freedom | Genotype | Mean Square (MS) |
|-------------|--------|------------------|----------|-----------------|
|             |        |                  |          | BpB | PB | DB | JBP | BBpT |
| Genotype    |        |                  |          |     |    |    |     |      |
|             |        |                  |          | 20  | 1.05**| 1.54**| 1.32*| 11931.57**| 5744.70**|
|             |        |                  |          | 5   | 1.31**| 1.72**| 1.48**| 4520.50ns  | 660.32ns  |
|             |        |                  |          | 15  | 0.03ns| 0.11**| 0.06ns| 3791.46**| 2331.64**|
| Error       |        |                  |          | 40  | 0.07 | 0.10 | 0.39 | 3275.19   | 1764.90   |
| Additive var|        |                  |          |     | 0.34 | 0.43 | 0.34 | 183.72    | -416.07   |
| Dominant var|        |                  |          |     | 0.02 | 0.07 | -0.04| 2701.50   | 1745.00   |
| CV (%)      |        |                  |          | 11.29 | 7.44 | 6.73 | 27.00| 23.50     |            |

Note: BpB: weight per one fruit; PB: fruit length; DB: fruit diameter; JBP: fruit number per plant, BBpT: fruit weight per plant; *) significant at 5% level; **) significant at 1% level, ns: no significant

Table 2. General (GCA) and specific combining ability (SCA) value of six local cayenne pure lines

| Genotype | Yield component and plant yield | BpB (g) | PB (cm) | DB (mm) | JBP (fruit unit) | BBpT (g) |
|----------|---------------------------------|--------|--------|--------|-----------------|--------|
| GCA      |                                 |        |        |        |                 |        |
| BNT      |                                 | -0.23  | -0.35  | -0.35  | -10.57          | -6.04  |
| GNY      |                                 | -0.31  | -0.36  | -0.42  | -16.24          | -7.25  |
| SGT      |                                 | -0.29  | -0.37  | -0.34  | -14.71          | -9.29  |
| BGJ      |                                 | 0.74   | 0.77   | 0.57   | -18.78          | 13.83  |
| HIU      |                                 | 0.11   | 0.32   | 0.42   | 24.60           | 2.26   |
| MDN      |                                 | -0.03  | -0.01  | 0.12   | 35.69           | 6.50   |
| SCA      |                                 |        |        |        |                 |        |
| BNT x GNY|                                 | -0.04  | 0.03   | 0.16   | -1.08           | -9.63  |
| BNT x SGT|                                 | 0.18   | 0.50   | 0.26   | -40.62          | -15.51 |
| BNT x BGJ|                                 | 0.00   | -0.41  | 0.41   | 42.70           | 47.73  |
| BNT x HIU|                                 | 0.02   | 0.14   | -0.41  | -64.18          | -31.71 |
| BNT x MDN|                                 | 0.16   | 0.24   | 0.35   | 77.23           | 55.00  |
| GNY x SGT|                                 | -0.07  | -0.26  | -0.13  | 26.32           | -17.63 |
| GNY x BGJ|                                 | -0.04  | 0.35   | -0.29  | 43.88           | 56.09  |
| GNY x HIU|                                 | 0.12   | 0.22   | -0.07  | 8.51            | 24.81  |
| GNY x MDN|                                 | 0.12   | 0.29   | 0.04   | -8.33           | 33.67  |
| SGT x BGJ|                                 | -0.18  | -0.16  | 0.15   | 0.10            | 34.94  |
| SGT x HIU|                                 | 0.27   | 0.56   | 0.06   | 35.23           | 69.90  |
| SGT x MDN|                                 | -0.04  | -0.20  | -0.10  | -22.12          | -8.69  |
| BGJ x HIU|                                 | 0.12   | 0.06   | -0.13  | 129.29          | 26.95  |
| BGJ x MDN|                                 | 0.09   | -0.10  | -0.10  | 38.45           | 2.23   |
| HIU x MDN|                                 | 0.21   | 0.08   | 0.48   | -37.18          | 18.21  |

Note: BpB: weight per one fruit; PB: fruit length; DB: fruit diameter; JBP: fruit number per plant, BBpT: fruit weight per plant

In Table 1 could be seen also that parameters of fruit number per plant (JBP) and fruit weight per plant (BBpT) showed that the dominant variant was higher than additive variant. This information was very important for breeding program because a new F-1 hybrid variety just could be done if the dominant variance of a character was higher than the additive. Heterosis effect occurrence caused by combining dominant genes according to heterozigous theory [21-22]. Thus, possibility obtaining a new F-1 hybrid variety was higher especially focussing to character fruit number and fruit weight per plant.
In the Table 2 could be known that BGJ line had the highest GCA value on several observed parameter i.e. weight per one fruit (0.74), fruit length (0.77), fruit diameter (0.57), and fruit weight per plant (13.83), while the highest GCA value on fruit number per plant was MDN line (35.69). Daryanto et al. [23] stated that a high GCA value of a parent line indicated that the line had good combining ability with others to obtain a F-1 hybrid progeny. Information of GCA value could be utilized in parent lines selection with consideration the breeding purpose. On plant height and flowering time usually the breeders expected low-negative GCA value, but contrary on yield and component yield were expected high-possitive GCA because more advantage in the F-1 hybrid variety [24].

F-1 SGT x HIU had the highest SCA value on weight per one fruit (BpB) (0.27), fruit length (PB) (0.56), and fruit weight per plant (BBpT) (69.90), while the highest SCA values on fruit diameter (DB) (0.48) and fruit number per plant (JBpT) (129.29) were obtained by F1 HIU x MDN and F-1 BGI x HIU respectively (Table 2). SCA with a high-positive value was obtained not only from crossing pollination both parents with positive GCA, but also between a positive GCA with a negative GCA value. In this case the dominant genes could hinder the disadvantage recessive genes and they were able to combine well [25].

3.2. Estimation value of heterosis and heterobeltiosis
F-1 hybrid genotype with positive heterosis and heterobeltiosis values was expected to increase the yield and component yield, but if a desired traits decreased, possibility heterosis tends to negative value [10]. In the Table 3 could be seen that the heaviest for weight of one fruit was F-1 BGJ x HIU (3.05 g), but heterobeltiosis value was negative. It’s meaning that the genotype’s vigor hybrid was not higher than the best parent value. There were four hybrid genotypes had high heterosis and heterobeltiosis value of the parameter i.e F-1 HIU x MDN, F-1 SGT x HIU, F-1 BNT x SGT, F-1 BNT x MDN. The F-1 HIU x MDN was the highest value of heterosis (30.96%) and heterobeltiosis (25.79%) respectively.

Table 3. Weight of one fruit of P1 (female parent), P2 (male parent), F1 and the heterosis-heterobeltiosis value

| Genotype   | Weight of one fruit (g) | Heterosis (%) | Heterobeltiosis (%) |
|------------|-------------------------|---------------|---------------------|
|            | P1         | P2          | F1               |                   |
| BNT x GNY  | 1.45       | 1.40        | 1.50 fg          | 5.26              | 3.45               |
| BNT x SGT  | 1.45       | 1.44        | 1.75 efg         | 21.11             | 20.69              |
| BNT x BGJ  | 1.45       | 3.55        | 2.60 bc          | 4.00              | -26.76             |
| BNT x HIU  | 1.45       | 1.90        | 1.93 de          | 15.22             | 1.58               |
| BNT x MDN  | 1.45       | 1.75        | 1.96 de          | 22.50             | 12.00              |
| GNY x SGT  | 1.40       | 1.44        | 1.41 g           | -0.70             | -2.08              |
| GNY x BGJ  | 1.40       | 3.55        | 2.48 bc          | 0.20              | -30.14             |
| GNY x HIU  | 1.40       | 1.90        | 2.01 de          | 21.82             | 5.79               |
| GNY x MDN  | 1.40       | 1.75        | 1.87 ef          | 18.73             | 6.86               |
| SGT x BGJ  | 1.44       | 3.55        | 2.37 cd          | -5.01             | -33.24             |
| SGT x HIU  | 1.44       | 1.90        | 2.13 cde         | 27.54             | 12.11              |
| SGT x MDN  | 1.44       | 1.75        | 1.73 efg         | 8.46              | -1.14              |
| BGJ x HIU  | 3.55       | 1.90        | 3.05 a           | 11.93             | -14.08             |
| BGJ x MDN  | 3.55       | 1.75        | 2.85 ab          | 7.55              | -19.72             |
| HIU x MDN  | 1.90       | 1.75        | 2.39 cd          | 30.96             | 25.79              |

Note: Mean followed by the same letters on the same columns are not significantly according to Duncan’s multiply range test at 0.05 level

In the Table 4 could be known that fruit number per plant of all parents had a mean range of 145.00-252.25, while all the hybrid genotypes had range of 146.25-331.25. Heterosis value of fruit number per plant ranged of -22.21 - 71.70%, whereas heterobeltiosis ranged of -29.06 – 51.60%.
There were eleven hybrids with positive heterosis and ten with positive heterobeltiosis. The F-1 BGJ x HIU, both of heterosis (71.70%) and heterobeltiosis (51.60%), was the highest for this character. In this research, dominant variant was higher than additive for this character. It proved dominant gene action on the character. There were an interaction between dominant genes in the different locus. At the end the dominant genes would combine in the F-1 hybrid when two pure lines were crossed pollination until caused heterosis or heterobeltiosis phenomenon [26].

Table 4. Fruit number per plant of P1 (female parent), P2 (male parent), F1 and the heterosis-heterobeltiosis value

| Genotype   | Fruit number per plant (fruit unit) | Heterosis (%) | Heterobeltiosis (%) |
|------------|-------------------------------------|---------------|---------------------|
|            | P1        | P2        | F1            |                |                |
| BNT x GNY  | 180.00    | 145.00    | 180.25 c      | 10.92          | 0.14           |
| BNT x SGT  | 180.00    | 177.25    | 146.25 c      | -18.12         | -18.75         |
| BNT x BGJ  | 180.00    | 167.35    | 225.00 bc     | 29.55          | 25.00          |
| BNT x HIU  | 180.00    | 218.50    | 155.00 c      | -22.21         | -29.06         |
| BNT x MDN  | 180.00    | 252.25    | 308.50 ab     | 47.24          | 22.30          |
| GNY x SGT  | 145.00    | 177.25    | 206.50 bc     | 28.16          | 16.50          |
| GNY x BGJ  | 145.00    | 167.35    | 220.00 bc     | 40.87          | 31.46          |
| GNY x HIU  | 145.00    | 218.50    | 228.00 bc     | 25.45          | 29.06          |
| GNY x MDN  | 145.00    | 252.25    | 215.25 bc     | 8.37           | -14.67         |
| SGT x BGJ  | 177.25    | 167.35    | 177.75 c      | 3.16           | 0.28           |
| SGT x HIU  | 177.25    | 218.50    | 256.25 abc    | 29.50          | 17.28          |
| SGT x MDN  | 177.25    | 252.25    | 214.00 bc     | -0.35          | -15.16         |
| BGJ x HIU  | 167.35    | 218.50    | 331.25 a      | 71.70          | 51.60          |
| BGJ x MDN  | 167.35    | 252.25    | 257.00 abc    | 22.50          | 1.88           |
| HIU x MDN  | 218.50    | 252.25    | 222.25 abc    | -5.58          | -11.89         |

Note: Mean followed by the same letters on the same columns are not significantly according to Duncan’s multiply range test at 0.05 level

Table 5. Fruit weight per plant of P1 (female parent), P2 (male parent), F1 and the heterosis-heterobeltiosis value

| Genotype   | Fruit weight per plant (g) | Heterosis (%) | Heterobeltiosis (%) |
|------------|----------------------------|---------------|---------------------|
|            | P1        | P2        | F1            |                |                |
| BNT x GNY  | 142.35    | 118.00    | 155.60 bc     | 19.53          | 0.77           |
| BNT x SGT  | 142.35    | 131.40    | 150.60 c      | 10.03          | 5.80           |
| BNT x BGJ  | 142.35    | 122.20    | 239.03 ab     | 80.71          | 67.92          |
| BNT x HIU  | 142.35    | 129.90    | 147.03 c      | 8.01           | 3.29           |
| BNT x MDN  | 142.35    | 141.25    | 235.98 ab     | 66.42          | 65.77          |
| GNY x SGT  | 118.00    | 131.40    | 148.34 c      | 18.96          | 12.89          |
| GNY x BGJ  | 118.00    | 122.20    | 243.18 a      | 102.48         | 99.00          |
| GNY x HIU  | 118.00    | 129.90    | 205.34 abc    | 65.66          | 58.08          |
| GNY x MDN  | 118.00    | 141.25    | 213.25 abc    | 64.51          | 50.97          |
| SGT x BGJ  | 131.40    | 122.20    | 222.00 abc    | 75.08          | 68.95          |
| SGT x HIU  | 131.40    | 129.90    | 243.42 a      | 86.31          | 85.25          |
| SGT x MDN  | 131.40    | 141.25    | 172.05 abc    | 26.21          | 0.86           |
| BGJ x HIU  | 122.20    | 141.25    | 207.07 abc    | 57.20          | 46.60          |
| BGJ x MDN  | 122.20    | 129.90    | 223.60 abc    | 77.39          | 72.13          |
| HIU x MDN  | 129.90    | 141.25    | 203.49 abc    | 50.09          | 44.06          |

Note: Mean followed by the same letters on the same columns are not significantly according to Duncan’s multiply range test at 0.05 level
In Table 5 could be seen that the fruit weight per plant of all parents ranged of 118.00 - 142.35 g, whereas the hybrid genotypes ranged of 147.03-243.42 g. Therefore all hybrids had a fruit weight per plant higher than mean of two parents even the best parent. It was showed by positive value of heterosis and heterobeltiosis. F-1 SGT x HIU and F-1 GNY x BGJ were higher of heterosis and heterobeltiosis value for fruit weight per plant. Iriany et al. [25] stated that a vigor hybrid with high heterosis and heterobeltiosis value was due to the genetic distance between the used parents was not too close or distinct.

3.3. The yield evaluation of F-1 hybrids cayenne compared with the commercial variety

In Table 6 could be seen that several F-1 genotypes had different significantly with STK as a commercial variety on weight per one fruit, fruit length, fruit diameter, fruit number per plant, and fruit weight per plant. Nevertheless according to result of variance analysis in the Table 1 informed that the dominant variant on fruit number and fruit weight per plant was higher than the additive variant. Thus in theory heterosis effect can occur caused by combining dominant genes. Hence fruit number and weight per plant could be focused as a main parameter for selecting. Genotype F-1 BNT x MDN (308.50), F-1 SGT x HIU (256.25), and F-1 BGJ x MDN (257.00) were different significantly with STK variety (223.10) on fruit number per plant. The consequence fruit weight per plant parameter among them was higher and different significantly also with STK variety (207.35 g). Nevertheless a F-1 hybrid variety did not focus to yield quantity only, but yield quantity also. Mostly consumers preferred cayenne with ideotype bright red color [27] middle size fruit, and pungency is hot [28]. This criteria become important for selection and evaluation in the preference test on advance test.

Table 6. Yield variance of six local cayenne pure lines and one F-1 commercial as reference variety

| Genotype     | BpB (g) | PB (cm) | DB (mm) | JBP T | BBpT (g) |
|--------------|---------|---------|---------|-------|---------|
| BNT x GNY    | 1.50    | 4.25    | 8.52    | 180.25| 155.60  |
| BNT x SGT    | 1.75    | 4.67 a  | 8.68    | 146.25| 150.60  |
| BNT x BGJ    | 2.60 a  | 4.90 a  | 9.68    | 225.00| 239.03 a|
| BNT x HIU    | 1.93    | 5.00 a  | 8.76    | 155.00| 147.03  |
| BNT x MDN    | 1.96    | 4.75 a  | 9.23    | 308.50 a| 235.98 a|
| GNY x SGT    | 1.41    | 3.90    | 8.22    | 206.50| 148.34  |
| GNY x BGJ    | 2.48 a  | 5.65 a  | 8.96    | 220.00| 243.18 a|
| GNY x HIU    | 2.01    | 5.02 a  | 9.04    | 228.00| 205.34  |
| GNY x MDN    | 1.87    | 4.81 a  | 8.84    | 215.25| 213.25  |
| SGT x BGJ    | 2.37 a  | 5.10 a  | 9.52    | 177.75| 222.00 a|
| SGT x HIU    | 2.13 a  | 5.40 a  | 9.22    | 256.25 a| 243.42 a|
| SGT x MDN    | 1.73    | 4.31    | 8.79    | 214.00| 172.05  |
| BGJ x HIU    | 3.05 a  | 6.01 a  | 9.97 a  | 331.25 a| 207.07 a|
| BGJ x MDN    | 2.85 a  | 5.55 a  | 9.70    | 257.00 a| 223.60 a|
| HIU x MDN    | 2.39 a  | 5.28 a  | 10.15 a | 222.25| 203.49  |
| STK          | 1.50    | 3.80    | 8.94    | 223.10| 207.35  |

Note: BpB: weight per one fruit; PB: fruit length; DB: fruit diameter; JBP T: fruit number per plant, BBpT: fruit weight per plant. Mean followed by a letters on the same columns are different significantly with F-1 STK variety according to Dunnett test at 0.05

4. Conclusion

The results showed that: (1) BGJ line has the highest GCA value on several observed parameters i.e. weight per one fruit (0.74), fruit length (0.77), fruit diameter (0.57), and fruit weight per plant (13.83), while the highest GCA value for fruit number per plant was MDN line (35.69); (2) Genotype F-1 SGT x HIU had the highest SCA value for weight per one fruit (0.27), fruit length (0.56), and fruit
weight per plant (69.90), while the highest SCA values for fruit diameter (0.48) and fruit number per plant (129.29) were obtained by F1 HIU x MDN and F-1 BGJ x HIU respectively; (3) Genotype F-1 BNT x MDN, F-1 SGT x HIU, F-1 BGJ x MDN are recommended as advance hybrid lines according to variant analysis and value of GCA, SCA, heterosis-heterobeltiosis.

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References

[1] Arumingtyas, E.A., Kusnadi, J., Sari, D.R.T., and Ratih, N 2017 AIP Conference Proceedings 1908, 050002.
[2] Kantar, M.B., Anderson, J.E., Lucht, S.A., Mercer, K., Bernau, V., Case, K.A., Le, N.C., Frederiksen, M.K., DeKeyser, H.C., Wong, Z.Z., Hastings, J.C., and Baunbeu, D.J 2016 PlosOne Journal 11(8).
[3] Undang, M. Syukur, dan Sobir 2015 J. Agron Indonesia 43 (2) : 118-125.
[4] Indriani, R., Darma, R., Musa, Y., Tenriawaru, A.N., and Arsyad, M 2020 Bulgarian Journal of Agricultural Science. 26(3): 499-506.
[5] Sativa, M., Harianto, and Suryana, A 2017 International Journal of Agricultural System 5(2): 120-139.
[6] Justino, E.V., Fonseca, M.E.N., Ferreira, M.E., Boiteux, L.S., Silva, P.P., and Nascimento, W.M 2018 Genetics and Molecular Research. 17(1):gmr16039887.
[7] Abraham, S., Mandefro, N., and Sentayehu, A 2017 International Journal of Plant Breeding and Genetics 11(2): 63-70.
[8] Kalloo 1986 Vegetable breeding Volume 1 CRC press. Boca Raton, Florida.
[9] Fujimoto,R., Uezono, K., Ishikura, S., Osabe. K., Peacock, W.J., and Dennis, E.S 2018 Breeding Science. 68:145-158
[10] Kirana, R. and Sofiari, E 2007 J. Hort. 17(2): 111-117.
[11] Herison, C., Fahrurrozi, and Handajaningsih, M 2016 Proceding ISEPROLOCAL: 192-196.
[12] Ngozi, A.E., Udoh, O.E., and Uguru M 2019 Journal of Plant Breeding and Crop Science 11(1): 11-16
[13] Gull, A., Lone, A.A., and Wani, N.U.I 2019 Biotic and abiotic Stresses in plants.
[14] Sitaresmi, T., Sujiprihati, S., and Syukur, M 2010 J. Agron. Indonesia 38(3): 212-217.
[15] Sharma, G.S. and R.B. Singh 1978 Indian J. Agric. Sci. 486: 515-570.
[16] Ahmed, S., M.S. Khan, M.S. Swati, G.S. Shah and I.H.Khalil 2005 J. Sci. Technol 27 (1): 1-8.
[17] Syukur, M., S. Sujiprihati, R. Yunianti 201 Teknik Pemuliaan Tanaman Penebar Swadaya. Jakarta.
[18] Daryanto, A., Syukur, M., Maharjaya, A., and Hidayat, P 2018 Journal ATJ. 3(2): 61-68.
[19] Fasahat, P., Rajabi, A., Rad, J.M., and Dereva, J 2016 Biometrics & Biostatistics International Journal 4(1):1-22.
[20] Hafsah, S., S. Sastrosumarjo, S. Sujiprihati, Sobir, S.H. Hidayat 2007 Bal. Agron 35(3):197-204.
[21] Yora, M., Ardi, P.F., Darniawati, Swasti, E 2017 Prosiding Seminar Nasional PERIPI p 58-64.
[22] Bouchetat, F., and Aissat A 2019 Heliyon Journal 5(2019)e02744.
[23] Daryanto, A., Sujiprihati, S., and Syukur, M 2010 Jurnal Agron. Indonesia 38(2): 113-121.
[24] Widyaastuti, Y., Purwoko, B.S., Yunus, M., Kartina, N., Wibowo, B.P., Rumanti, I.A., and Satoto 2017 Penelitian Pertanian Tanaman Pangan. 1(3): 173-181
[25] Iriany, R.N., S. Sujiprihati, M. Syukur, J. Koswara, M. Yunus 2011 J. Agron. Indonesia 39(2):103-111.
[26] Tiwari, D.K., Pandey, P., Giri, S.P., and Dwivedi, J.L 2011 J of Plant Sci 10(1):29-42.
[27] Lannes, S.D., Finger, F.L., Schuetler, A.R., and Casali, V.W.D 2007 Sci. Hort 112:266-270.
[28] Sota, Y. 2013 Occasional Paper, 53:77-89