ISSN 1819-1894

Asian Journal of Agricultural Research

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

OPEN ACCESS Asian Journal of Agricultural Research

ISSN 1819-1894
DOI: 10.3923/ajar.2017.10.17

Research Article
Inheritance of Fruit Cracking Resistance in Tomato (*Solanum lycopersicum* L.)

[1]Marlina Mustafa, [2]Muhamad Syukur, [2]Surjono Hadi Sutjahjo and [2]Sobir

[1]Department of Agrotechnology, Faculty of Agriculture, Fishery and Animal Science, Sembilanbelas November University, Kolaka, Jl. Pemuda No. 399 Kolaka, 93514 Southeast Sulawesi, Indonesia
[2]Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti, Kampus IPB Darmaga, 16680 Bogor, Indonesia

Abstract

Background: The agri-food industry has prioritized varieties with good quality fruit of vegetables such as tomatoes. Tomato fruit cracking is a physiological disorder that occurs due to genetic and environmental factors and causes fruit damage and reduce fruit quality, resulting in great economic losses. **Objective:** The objective of this study was to identify genotypes resistant and susceptible, determine selection criteria for fruit cracking resistance, inheritance of tomato fruit cracking and determine the selection method to develop superior tomatoes that are reistant to tomato fruit cracking. **Material and Methods:** A randomized complete block design was used to select parental plants based on fruit cracking index and determine the selection criteria based on correlation analysis, path analysis and heritability. Resistant genotype and susceptible genotype used as parent in six generation with Mendel analysis were used to determine the inheritance of tomato fruit cracking. **Results:** Results showed that the resistance genotypes to fruit cracking are IPBT4, IPBT56, IPBT60, IPBT64, IPBT83 and IPBT85 and the susceptible genotype in IPBT3. The resistance genotypes can be used as a donor parent for superior genotypes and fruit cracking resistance. The number of locales and pericarp thickness can be used as selection criteria for fruit cracking resistance because these have a high direct influence on fruit cracking and high heritability. Inheritance of tomato fruit cracking controlled by two pairs of double resessive epistasis gene or complete dominance. **Conclusion:** The pedigree selection will be the best breeding method to develop good line bred varieties with fruit cracking resistance.

Key words: Fruit cracking, gene action, heritability, inheritance, path analysis, six generations

Received: July 20, 2016 Accepted: October 10, 2016 Published: December 15, 2016

Citation: Marlina Mustafa, Muhamad Syukur, Surjono Hadi Sutjahjo and Sobir, 2017. Inheritance of fruit cracking resistance in tomato (*Solanum lycopersicum* L.). Asian J. Agric. Res., 11: 10-17.

Corresponding Author: Muhamad Syukur, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Indonesia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of superior horticulture commodities that has high nutrient content, is cultivated widely around the world and constitutes a major agricultural industry and it is the second most consumed vegetable after potato[1]. It can be consumed freshly or after further manufacturing processes and hence it has a good market prospect. One of the biggest problems in tomato cultivation is fruit cracking. Fruit cracking in tomatoes that are of freshly consumed type can reduce the appearance of tomato, leading to reduction in the amount of fruit that is marketed. Regarding the processed tomato type, cracking can allow the entry of pathogens, thereby resulting in a significant loss of yield[2-7].

Fruit cracking is a physiological disorder and a complex phenomenon caused by several factors. It occurs because of the changes in the rapid growth rate of the fruit due to genetic and environmental factors[8]. Tomatoes that are susceptible to fruit cracking exhibit a large size, a thin rind, a thin pericarp and less number of fruit per plant[9]. Fruit cracking in chilli is correlated with fruit length, fruit diameter and length-to-diameter ratio of the fruit[10].

Environmental factors that influence fruit cracking include rainfall, temperature, light intensity and humidity[3,11-14], which are difficult to control. Cultivation technique treatments can reduce the losses caused by fruit cracking. However, such treatments are temporary and ineffective because they need to be done in every planting season and are expensive. The use of resistant varieties against fruit cracking is a more effective solution[13]. Genetic analysis of resistance to fruit cracking is an initial strategy of selection to produce resistant varieties[15].

Information regarding studies of inheritance pattern of resistance to fruit cracking has been inconsistent. The AVRDC[16] reported that fruit cracking in tomato is controlled by a single simple gene. According to Young[17], the radial type fruit cracking is controlled by two pairs of a major gene, which are *cr cr* and *lr lr*. Furthermore, Amstrong and Tompson[18] and Hernandez and Nassar[19] concluded that fruit cracking in tomato is controlled by multiple genes that have a partial dominant trait. Fruit cracking in chilli is dominant with some additive effect[10]. Emmons and Scot[3] proved that controlling fruit cracking genes is quantitative (polygenic).

The first step in plant breeding for the resistant varieties is establishment of a base population with high diversity, which begins with the collection of various genetic resources and then screening them to identify the resistance genotypes[20,21]. The availability of genetic diversity will determine the success of breeding programs[22]. The success of the assembly plant is determined by the selection method and the appropriate selection criteria[20,23,24]. The characters used as selection criteria should be selected based on the value of heritability as well as the relationship with the desired character[25]. Correlation and path analysis is a method that is widely used to study the relationship of closeness between the characters to develop selection criteria and this method has been used on a variety of crops, including tomato[26] and chilli[27]. The use of the correct selection method to obtain a desired character requires information about the pattern of inheritance of the character. This information is very useful in the selection process so that the selection is more effective and efficient. Therefore, it is essential to investigate the inheritance pattern of fruit cracking resistance in tomato. The aim of this study was to identify fruit cracking resistance genotypes and determine the selection criteria and the inheritance pattern of fruit cracking resistance in tomato, so that the appropriate method for selecting the tomato varieties resistant to fruit cracking can be recommended.

MATERIALS AND METHODS

Plant material and experimental design: The experimental material consisted of genetically diverse 30 genotypes, viz., IPBT1, IPBT3, IPBT4, IPBT6, IPBT8, IPBT13, IPBT21, IPBT23, IPBT26, IPBT30, IPBT33, IPBT34, IPBT43, IPBT53, IPBT56, IPBT57, IPBT58, IPBT59, IPBT60, IPBT63, IPBT64, IPBT73, IPBT74, IPBT78, IPBT80, IPBT82, IPBT83, IPBT84, IPBT85 and IPBT86. The selected 30 genotypes with fruit cracking resistance were planted in a randomized complete block design with three replications. The selection results provided the genotypes resistant and susceptible to fruit cracking, which were used as a parent for assessing the inheritance pattern of tomato fruit cracking. Six generations of genetic populations (P1, P2, F1, BCP1, BCP2 and F2) with Mendel analysis were used to determine the inheritance pattern of fruit cracking in tomato. The P1 is the resistance genotype and P2 is the susceptible genotype for fruit cracking. P1, P2, F1 and F1R each consisted of 20 plants, F2 consisted of ±200 plants and BCP1 and BCP2 each consisted of 80 plants.

Observation of characters: The characters that were observed for selecting plants with fruit cracking were height of plant (cm), leaf length (cm), leaf width (cm), day to flowering (hst), day to harvesting (hst), fruit length (cm), fruit

diameter (cm), fruit size (cm), thickness of the flesh of fruit (mm), number of locules (locul), total soluble solids (brix), fruit hardness (kg cm^{-1}), water content of fruit (%), number of fruit per plant (fruit), weight per fruit (g), weight per plant (kg), percentage of fruit cracking per plant (%), weight percentage of fruit cracking per plant (%) and the primary character of Fruit Cracking Index (FCI). Calculation of fruit cracking index was done using the following formula[15]:

$$\text{Fruit cracking index} = 100 - \frac{\sum(\text{ni} \times \text{score})}{\sum \text{n} \times \text{maximum score}} \times 100\%$$

where, ni is the number of fruit in the score against i (i = 0, 1, 2, 3, 4, maximum score: 4).

The score value was determined based on "Crack resistance score" method[10,15,28-30] that was modified as follows: 0 = No fruit cracking, 1 = Little fruit cracking (<25%), 2 = Moderate fruit cracking (25–50%), 3 = A rather heavy fruit cracking (50–70%) and 4 = Heavy fruit cracking (>75%). Figure 1 shows an illustration of fruit cracking scores[29,30].

Data analysis: Data of 30 genotypes for selection of fruit cracking resistance were analyzed using analysis of variance (ANOVA). Significant data were analyzed by Duncan's significant difference at 5%. The ANOVA was also used to estimate heritability in a broad sense. Phenotype and genotype correlation analysis was conducted to determine the relationship between the characters and path analysis was used to determine the selection criteria that correlate directly with fruit cracking[24,25,31]. Inheritance pattern of fruit cracking was analyzed using six generations following the method of Qi *et al.*[15]. The qualitative characters of fruit cracking were analyzed using Mendel analysis.

RESULTS AND DISCUSSION

Selection of fruit cracking resistance genotypes: The results of ANOVA for the percentage of fruit cracking number and percentage of fruit cracking weight per plant in Table 1 indicate that there are differences in resistance to fruit cracking in the 30 tomato genotypes. Calculation of the fruit cracking index resulted in five groups of fruit cracking resistance, which were highly resistant, resistant, moderately resistant, slightly susceptible and susceptible. This shows that there was a genetic diversity in the tomato genotypes tested, with different resistance patterns against fruit cracking. Among the 30 genotypes, there were six genotypes that were resistant (IPBT4, IPBT56, IPBT60, IPBT64, IPBT83 and IPBT85)

Table 1: Fruit cracking index (FCI) of 30 genotypes of tomato

Genotypes	IPB	Criteria	No.	Genotypes	IPB	Criteria
IPB T1	86.72	SS	16	IPB T57	99.33	R
IPB T3	68.33	S	17	IPB T58	98.07	R
PB T4	100.00	HR	18	IPB T59	99.67	R
IPB T6	99.70	R	19	IPB T60	100.00	HR
IPB T8	98.32	R	20	IPB T63	99.29	R
IPB T13	85.59	SS	21	IPB T64	100.00	HR
IPB T21	89.05	SS	22	IPB T73	83.66	SS
IPB T23	98.37	R	23	IPB T74	98.50	R
IPB T26	98.74	R	24	IPB T78	99.56	R
IPB T30	88.29	SS	25	IPB T80	99.79	R
IPB T33	80.84	SS	26	IPB T82	99.76	R
IPB T34	94.35	MR	27	IPB T83	100.00	HR
IPB T43	94.08	MR	28	IPB T84	99.84	T
IPB T53	97.35	R	29	IPB T85	100.00	HR
IPB T56	100.00	HR	30	IPB T86	85.51	SS

HR: Highly resistant, R: Resistant, MR: Moderately resistant, SS: Slightly susceptible, S: Susceptible

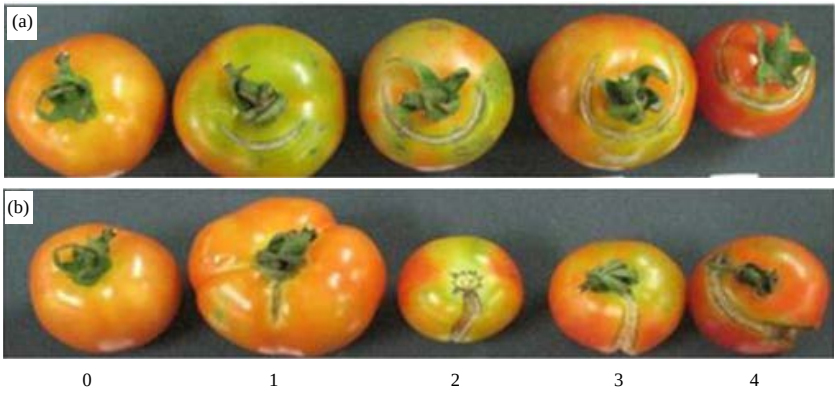

Fig. 1(a-b): Scoring illustration of fruit cracking (a) Concentric fruit cracking and (b) Radial fruit cracking

and one susceptible genotype (IPBT3). There was no genotype that qualified as highly resistant. In this study, one of the resistant genotypes and the susceptible genotype were used as a parent for artificial crossing to assess the inheritance pattern of fruit cracking resistance, which would facilitate choosing the appropriate selection method for obtaining plants resistant to fruit cracking.

Heritability: The key to success of the selection method was determined by the appropriate selection criteria. Heritability is one of the variables that can be used as a selection criterion because it can provide an overview of the extent of the observed appearance (phenotype), which is a reflection of the genetic influence[24]. Characters that indicated a high broad sense heritability values were plant height, leaf length, leaf width, fruit length, fruit diameter, fruit size, thickness of the flesh of fruit, number of locules, fruit hardness, number of fruit per plant, weight per fruit, weight per plant and fruit cracking index. Characters indicating moderate heritability values were day to flowering, day to harvesting, total soluble solids and water content of fruit (Table 2).

For the selection criteria, characters that showed high heritability estimates and significantly correlated with fruit cracking index were used. The heritability estimates could be used to select the characters that would be used as the selection criteria[32,33]. The heritability estimates with high selection criteria could be directly used for character selection in the initial generations[34,35]. Some other studies on tomato also showed high heritability values in the character number of flowers per bunches[36], the locule number[37] and the number of fruit per bunch[38]. The high broad sense heritability implies that the character was observed and controlled more by genetic factors rather than by environmental factors and the genetic diversity was expressed in the plant phenotypic appearance[20]. Emmons and Scott[3] showed a high level of broad sense heritability for cuticle-cracking incidence in tomato.

Phenotype and genotype correlation: Correlation results of phenotype and genotype showing the relationship among the characters are presented in Table 3. The results of phenotype correlation showed that leaf length, leaf width, fruit hardness,

Table 2: Heritability of some tomato characters

Characters	h^2bs	Criteria	Character	h^2bs	Criteria
Plant height	0.76	High	Locule number	0.97	High
Leaf length	0.75	High	Total soluble solids	0.35	Moderate
Leaf width	0.75	High	Fruit hardness	0.70	High
Day to flowering	0.39	Moderate	Water content of fruit	0.38	Moderate
Day to harvesting	0.41	Moderate	Number of fruit per plant	0.85	High
Fruit length	0.92	High	Weight per fruit	0.93	High
Fruit diameter	0.91	High	Weight per plant	0.62	High
Fruit size	0.89	High	Fruit cracking index	0.96	High
Thickness of the flesh of fruit	0.82	High			

h^2bs: Broad sense heritability

Table 3: Phenotype and genotype correlation among characters with fruit cracking

Characters	PH	LL	LW	DF	DH	FL	FD	FS	TFF	NL	TSS	FH	WC	NFP	WPF	WPF	FCI
PH	1.00	−0.11^{sn}	−0.25*	0.16^{ns}	−0.17^{ns}	−0.1^{ns}	0.39**	0.13^{ns}	0.00^{ns}	0.48**	0.05^{ns}	0.13^{ns}	0.06^{ns}	−0.20^{ns}	0.24*	0.20^{ns}	−0.06^{ns}
LL	0.08^{ns}	1.00	0.85**	0.15^{ns}	0.35**	0.56**	0.06^{ns}	0.41**	0.50**	−0.41**	0.25*	0.20^{sn}	−0.21*	−0.36**	0.28*	−0.18^{ns}	0.40**
LW	−0.02^{ns}	0.97**	1.00	0.09^{ns}	0.27*	0.47**	−0.07^{ns}	0.29*	0.50**	−0.43**	0.16^{ns}	0.21^{ns}	−0.20^{ns}	−0.20^{ns}	0.15^{ns}	−0.11^{ns}	0.32**
DF	0.43*	0.76**	0.67**	1.00	0.41**	0.47**	0.20^{ns}	0.43**	0.39**	−0.14^{ns}	0.19^{ns}	0.30**	−0.21^{ns}	−0.33**	0.37**	−0.01^{ns}	0.29*
DH	0.29^{ns}	0.81**	0.67**	0.98**	1.00	0.55**	0.27*	0.52**	0.37**	−0.21^{ns}	0.25*	0.27*	−0.27*	−0.45**	0.44**	−0.16^{ns}	0.38**
FL	0.08^{ns}	0.78**	0.69**	0.76**	0.76**	1.00	0.32**	0.86**	0.80**	−0.39**	0.33**	0.39**	−0.43**	−0.69**	0.54**	−0.12^{ns}	0.60**
FD	0.65**	0.38*	0.22^{ns}	0.22^{ns}	0.63**	0.48**	1.00	0.76**	0.43**	0.65**	−0.06^{ns}	0.00^{ns}	−0.02^{ns}	−0.59**	0.71**	0.38**	0.07^{ns}
FS	0.38*	0.69**	0.55**	0.80**	0.80**	0.92**	0.84**	1.00	0.78**	0.08^{ns}	0.19^{ns}	0.27*	−0.31**	−0.79**	0.76**	0.12^{ns}	0.45**
TFF	0.19^{ns}	0.76**	0.71**	0.75**	0.70**	0.92**	0.61**	0.91**	1.00	−0.22**	0.16^{ns}	0.28*	−0.41**	−0.62**	0.46**	−0.02^{ns}	0.58**
NL	0.63**	−0.27^{ns}	−0.33^{ns}	0.06^{ns}	0.04^{ns}	−0.30^{ns}	0.68**	0.15^{ns}	−0.13^{ns}	1.00	−0.25*	−0.28*	0.34**	−0.04^{ns}	0.25*	0.49**	−0.38**
TSS	0.39*	0.77**	0.66**	0.99**	0.95**	0.74**	0.49**	0.71**	0.65**	−0.04^{ns}	1.00	0.40**	−0.22*	−0.33**	0.16^{ns}	−0.38**	0.28*
FH	0.25^{ns}	0.48**	0.55**	0.71**	0.70**	0.66**	0.32^{ns}	0.59**	0.61**	−0.20^{ns}	0.72	1.00	−0.37**	−0.31**	0.23*	−0.28^{ns}	0.31**
WC	0.36*	0.57**	0.51**	0.87**	0.91**	0.41*	0.52**	0.50**	0.42*	0.25^{ns}	0.90**	0.44*	1.00	0.29^{ns}	−0.25*	0.07^{ns}	−0.49**
NFP	−0.22^{ns}	−0.49**	−0.29^{ns}	−0.57**	−0.80**	−0.78**	−0.66**	−0.91**	−0.72**	−0.04^{ns}	−0.67**	−0.46*	0.47**	1.00	−0.72**	0.17^{ns}	−0.49**
WPF	0.26^{ns}	0.34^{ns}	0.15^{ns}	0.58**	0.67**	0.58**	0.76**	0.82**	0.51**	0.24^{ns}	−0.36*	0.33^{ns}	−0.41*	−0.81**	1.00	0.34**	0.31**
WPP	0.26^{ns}	−0.35^{ns}	−0.31^{ns}	−0.17^{ns}	−0.43*	−0.18^{ns}	0.47**	0.13^{ns}	−0.06^{ns}	0.62**	−0.64**	−0.33^{ns}	0.15^{ns}	0.07^{ns}	0.31^{ns}	1.00	−0.29*
FCI	−0.06^{sn}	0.47**	0.37*	0.53**	0.62**	0.64**	0.09^{ns}	0.50**	0.65**	−0.39*	0.48**	0.36*	−0.80**	−0.54**	0.34^{ns}	−0.35^{ns}	1.00

*Significant, **Highly significant, ^{ns}Not significant, PH: Plant height, LL: Leaf length, LW: Leaf width, DF: Day to flowering, DH: Day to harvesting, FL: Fruit length, FD: Fruit diameter, FS: Fruit size, TFF: Thickness of the flesh o f fruit, NC: No. of locules, TSS: Total soluble solids, FH: Fruit hardness, WC: Water content of fruit, NFP: No. of fruit per plant, WPF: Weight per fruit, WPP: Weight per plant, FCI: Fruit cracking index. Phenotype correlation values: Upper right diagonal, genotype correlation values: Lower left diagonal

day to harvesting, fruit length, fruit diameter, weight per plant, fruit size and thickness of the flesh of fruit have a positive significant correlation with fruit cracking index. However, the locule number, water content of fruit, number of fruit per plant and weight per plant showed a negative significant correlation with fruit cracking index. Genotype correlation also revealed similar results, except weight per fruit and weight per plant that were not significant. The positive correlation of the characters suggests that inclusion of these characters will increase the fruit cracking index. Similarly, inclusion of the negatively correlated characters would lower the fruit cracking index. These results show that genotypes with fruit cracking resistance exhibit lengthy and broad leaves, less number of days for flowering and harvesting, larger sized fruit, thicker fruit flesh, less locule number, high total soluble solids, high fruit thickness, low water content and less number of fruit per plant. Improvement of these characters would increase the resistance to fruit cracking. These findings were consistent with those reported by Wahyuni *et al.*[30] who showed that the characters leaf length, leaf width, day to flowering, day to harvesting and fruit length were correlated with fruit cracking.

Path analysis: The high correlation indicated only the close relationship between the characters but could not indicate the causality[24]. Path analysis could be used to determine the causality and could distinguish between direct and indirect influence[39]. The characters tested using path analysis were those that showed a significant correlation with the primary character (fruit cracking index). Based on the path analysis (Table 4), the characters that have a major influence on fruit cracking were leaf width, fruit length, thickness of the flesh of fruit, locule number, total soluble solids, number of fruit per plant and weight per plant. The characters leaf width, fruit size, number of fruit per plant and weight per fruit showed a direct influence that was negative, which implies that the indirect influence was the cause of the correlation[31].

The strategy to determine the characters that could be used as effective selection criteria could be derived from the magnitude of the direct influence on fruit cracking index, correlation between characters and fruit cracking index and correlation difference between free characters with the direct influence of those characters on fruit cracking index. If these tasks could be accomplished, then the highly efficient characters could be used as the selection criteria[24]. Based on that determination, the characters that contributed the largest direct influence and the total indirect small influence were the number of locules and thickness of the flesh of fruit. The path analysis scheme for identifying the characters related to fruit cracking index is shown in Fig. 2.

Based on the heritability value, correlation coefficients and path coefficient, the characters that could be used as the selection criteria for determining fruit cracking resistance were the locule number and thickness of the flesh of fruit. This observation was consistent with Peet[9] who reported that a thin fruit flesh was a fruit character that indicated susceptibility to fruit cracking.

Inheritance pattern of fruit cracking: The parents that were used for the analysis of gene action was the parent that was resistant to fruit cracking, based on the selection result in the previous study. The IPBTT64 (P1) as a resistant parent to fruit cracking and IPBT3 (P2) is a susceptible parent to fruit cracking. The results showed that the F1 generation and backcross to the female parent (BCP1) produced the plants that were resistant to fruit cracking.

Table 4: Direct and indirect influence of each character on fruit cracking index

Characters	Direct influence	LL	LW	DF	DH	PB	FS	TFF	NL	TSS	FH	WC	NFP	WPF	WPP	Total
LL	0.033		−0.002	0.000	0.000	0.004	−0.003	0.004	−0.006	0.001	0.000	0.000	0.002	0.000	0.001	0.032
LW	−0.087	−0.002		0.000	−0.001	−0.009	0.006	−0.009	0.017	−0.001	0.001	0.001	−0.003	0.000	−0.001	−0.089
DF	0.045	0.000	0.000		0.001	0.004	−0.005	0.004	−0.003	0.001	−0.001	0.000	0.003	0.000	0.000	0.049
DH	0.039	0.000	−0.001	0.001		0.004	−0.005	0.004	−0.004	0.001	0.000	0.000	0.003	0.000	0.001	0.042
FL	0.211	0.004	−0.009	0.004	0.004		−0.042	0.035	−0.038	0.004	−0.004	−0.003	0.027	−0.001	0.004	0.197
FS	−0.234	−0.003	0.006	−0.005	−0.005	−0.042		−0.035	−0.009	−0.003	0.003	0.003	−0.034	0.001	0.004	−0.353
TFF	0.235	0.004	−0.009	0.004	0.004	0.035	−0.035		−0.033	0.002	−0.003	−0.005	0.021	−0.001	0.004	0.223
NL	0.460	−0.006	0.017	−0.003	−0.004	−0.038	−0.009	−0.033		−0.007	0.006	0.006	0.003	−0.001	−0.033	0.359
TSS	0.063	0.001	−0.001	0.001	0.001	0.004	−0.003	0.002	−0.007		−0.001	0.000	0.004	0.000	0.004	0.066
FH	−0.048	0.000	0.001	−0.001	0.000	−0.004	0.003	−0.003	0.006	−0.001		0.001	−0.003	0.000	−0.002	−0.052
WC	0.036	0.000	0.001	0.000	0.000	−0.003	0.003	−0.005	0.006	0.000	0.001		−0.002	0.000	0.000	0.034
NFP	−0.184	0.002	−0.003	0.003	0.003	0.027	−0.034	0.021	0.003	0.004	−0.003	−0.002		−0.001	0.005	−0.159
WPF	−0.006	0.000	0.000	0.000	0.000	−0.001	0.001	−0.001	−0.001	0.000	0.000	0.000	−0.001		0.000	−0.008
WPP	−0.146	0.001	−0.001	0.000	0.001	0.004	0.004	0.004	−0.033	0.004	−0.002	0.000	0.005	0.000		−0.161

LL: Leaf length, LW: Leaf width, DF: Day to flowering, DH: Day to harvesting, FS: Fruit size, TFF: Thickness of the flesh of fruit, NL: No. of locules, TSS: Total soluble solids, FH: Fruit hardness, WC: Water content of fruit, NFP: No. of fruit per plant, WPF: Weight per fruit, WPP: Weight per plant

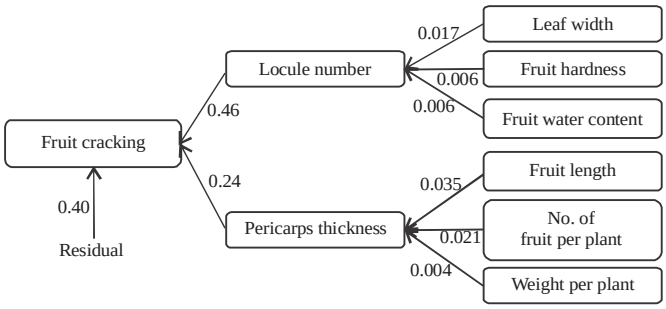

Fig. 2: Path analysis diagram of some characters against fruit cracking index

Table 5: Chi-square values of resistance to fruit cracking in P1, P2, BCP1, BCP2 and F2 generations

Generations	Phenotypes	Ratio	Expectance	Observation	χ^2 count	χ^2 tab
P1	100% resistant					
P2	100% susceptible					
F1	100% resistant					
BCP1	100% resistant					
BCP2	Resistant:Susceptible	1:3	17.75:53.25	27: 44	3.21^{ns}	3.84
F2	Resistant:Susceptible	9:7	102.94:80.06	115: 68	3.63^{ns}	3.84

χ^2 count: Chi-square test value, χ^2 tab: Table value, P1: Female parent, P2: Male parent, F1: First generation, F1R: First reciprocity generation, BCP1: Backcross to the female parent, BCP2: Backcross to the male parent, F2: Second generation

In the present study, the F1 and BCP1 generations skewed toward the resistant parent were obtained using the resistant parent IPBT64 hybridized with the susceptible parent IPBT3. The resistance of the BCP2 generation following hybridization was also skewed toward the susceptible parent. The F2 generation skewed toward the resistant parent, suggesting that fruit cracking resistance had a greater dominant effect than susceptibility, which is inconsistent with previous breeding experience, in which the F1 population showed a tendency toward either one of the parents with fruit cracking in breeding. However, the F1 generations of hybrid combinations from the resistant plants showed different degrees of fruit cracking[15].

The results of Mendel analysis in F2 generation showed that the ratio was 9 resistant: 7 cracking. Furthermore, the phenotype ratio in backcross population to male parent (BCP2) was 1 resistant: 3 cracking (Table 5). This showed that fruit cracking was controlled by two pairs of genes with double recessive epistasis or complete dominance by both complementary genes. When one of the genes was homozygous recessive, that gene suppressed or covered other phenotypic characters. The same phenotype was produced by both genotype homozygous recessives[40,41]. Complementation between certain dominant genes and other dominant genes was necessary. The illustration of resistant genotypes to fruit cracking was FC1-FC2-, whereas the susceptible genotypes to fruit cracking were FC1-fc2, fc1FC2- and fc1-fc2-. AVRDC[16], Young[17], Amstrong and Tompson[18] and Hernandez and Nassar[19] concluded that fruit cracking in tomato is controlled by single or multiple genes (qualitative) that have a partial dominant trait. Emmons and Scott[3] and Wahyuni *et al.*[30] proved that fruit cracking is controlled by polygenes (quantitative). Estimatation of gene effects indicated that dominant effects were the major contribution for pepper fruit cracking. However, there were also a significant additive effect and an epistatic effect in other parental plants[10]. The breeding method for the development of tomato plants resistant to fruit cracking was the pedigree method.

CONCLUSION

The genotypes that are resistant to fruit cracking based on the number of cracking fruit percentage, percentage of fruit weight and fruit cracking index were IPBT4, IPBT56, IPBT60, IPBT64, IPBT83 and IPBT85. The genotypes that are susceptible to fruit cracking was IPBT3. The number of locules and thickness of the flesh of fruit could be used as the selection criteria for fruit cracking because they have a high direct influence on fruit cracking index and have a high heritability. The fruit cracking index in tomato was controlled by two pairs of double recessive epistasis genes or complete domination by both the genes that were complementary. The selection method for the development of tomato resistant to fruit cracking was the pedigree method.

SIGNIFICANT STATEMENTS

The resistance genotypes to fruit cracking are IPBT64 and the susceptible genotype in IPBT3. The resistance genotypes can be used as a donor parent for superior genotypes and fruit cracking resistance. The number of locules and pericarp thickness can be used as selection criteria for fruit cracking resistance. Inheritance of tomato fruit cracking controlled by two pairs of double resessive epistasis gene or complete dominance. This is consistent with previous study show that fruit cracking resistance is controlled by two genes, but contrary to previous study says that the fruit cracking resistance gene controlled by single genes and other study show that the fruit cracking resistance of fruit controlled polygenic

ACKNOWLEDGMENTS

This study was financially supported by the Directorate General of Higher Education, Ministry of National Education of Indonesia, which has provided funding through the competitive grants in 2012 on behalf of Rahmi Yunianti with the project number 06/13.24.4/SPK-PUS-PUS/IPB/2012, which has provided funding through the competitive grants in 2012 by Dr. Rahmi Yunianti and BOPTN in 2013 by Dr. Syarifah Iis Aisyah with the project number 271/IT3.41.2/L2/SPK/2013. It is also to Ministry of Research and Technology through the Insinas Grant in 2014 on behalf of Sobir with the project number 25/SEK/INSINAS/PPK/2014.

REFERENCES

1. Akhtar, S. and P. Hazra, 2013. Nature of gene action for fruit quality characters of tomato (*Solanum lycopersicum*). Afr. J. Biotechnol., 12: 2869-2875.
2. Balbontin, C., H. Ayala, M.B. Richard, G. Tapia and M. Ellena *et al*., 2013. Cracking in sweet cherries: A comprehensive review from a physiological, molecular and genomic perspective. Chil. J. Agric. Res., 73: 66-72.
3. Emmons, C.L.W. and J.W. Scott, 1998. Diallel analysis of resistance to cuticle cracking in tomato. J. Am. Soc. Hortic. Sci., 123: 67-72.
4. Hahn, F., 2011. Fuzzy controller decreases tomato cracking in greenhouses. Comput. Electron. Agric., 77: 21-27.
5. Kong, M., B. Lampinen, K. Shackel and C.H.Crisosto, 2013. Fruit skin side cracking and ostiole-end splitting shorten postharvest life in fresh figs (*Ficus carica* L.), but are reduced by deficit irrigation. Postharvest Biol. Technol., 85: 154-161.
6. Lichter, A., O. Dvir, E. Fallik, S. Cohen, R. Golan, Z. Shemer and M. Sagi, 2002. Cracking of cherry tomatoes in solution. Postharvest Biol. Technol., 26: 305-312.
7. Matas, A.J., E.D. Cobb, D.J. Paolillo and K.J. Niklas, 2004. Crack resistance in cherry tomato fruit correlates with cuticular membrane thickness. HortScience, 39: 1354-1358.
8. Ehret, D.L., B.D. Hill, D.A. Raworth and B. Estergaard, 2008. Artificial neural network modelling to predict cuticle cracking in greenhouse peppers and tomatoes. Comput. Electron. Agric., 61: 108-116.
9. Peet, M.M., 1992. Fruit cracking in tomato. HortTechnology, 2: 216-223.
10. Johnson, D. and D.E. Knavel, 1990. Inheritance of cracking and scarring in pepper fruit. J. Am. Soc. Hortic. Sci., 115: 172-175.
11. Demirsoy, L. and H. Demirsoy, 2004. The epidermal characteristics of fruit skin of some sweet cherry cultivars in relation to fruit cracking. Pak. J. Bot., 36: 725-731.
12. Lane, W.D., M. Meheriuk and D.L. McKenzie, 2000. Fruit cracking of a susceptible, an intermediate and a resistant sweet cherry cultivar. HortScience, 35: 239-242.
13. Liebisch, F., J.F. Max, G. Heine and W.J. Horst, 2009. Blossom-end rot and fruit cracking of tomato grown in net-covered greenhouses in Central Thailand can partly be corrected by calcium and boron sprays. J. Plant Nutr. Soil Sci., 172: 140-150.
14. Max, J.F.J., W.J. Horst, U.N. Mutwiwa and H.J. Tantau, 2009. Effects of greenhouse cooling method on growth, fruit yield and quality of tomato (*Solanum lycopersicum* L.) in a tropical climate. Sci. Hortic., 122: 179-186.
15. Qi, Z., J. Li, M.A. Raza, X. Zou, L. Cao, L. Rao and L. Chen, 2015. Inheritance of fruit cracking resistance of melon (*Cucumis melo* L.) fitting E-0 genetic model using major gene plus polygene inheritance analysis. Scient. Hortic, 189: 168-174.
16. AVRDC., 1982. Tomato breeding. A Progress Report, Asian Vegetable Research and Development Center, Taiwan, pp: 1-27.
17. Young, H., 1959. Inheritance of radial fruit cracking in a tomato cross. Proc. Fla. State Hort. Soc., 72: 207-210.
18. Amstrong, R. and A. Tompson, 1967. A diallel analysis of tomato fruit cracking. Proc. Am. Soc. Hort. Sci., 91: 505-517.
19. Hernandez, T.P. and S.H. Nassar, 1970. Breeding tomatoes for radial fruit crack resistance and other characters. J. Am. Soc. Hort. Sci., 95: 223-226.
20. Syukur, M., S. Sujiprihati and R. Yunianti, 2015. Plant Breeding Techniques. Penebar Swadaya Publisher, Jakarta, Indonesia.
21. Zainal, A., A. Anwar, S. Ilyas, Sudarsono and Giyanto, 2011. [Inoculation test and response of 38 tomato genotypes to Indonesian isolates of *Clavibacter michiganensis* subsp. *michiganensis*]. Jurnal Agronomi Indonesia, 39: 85-91, (In Indonesian).
22. Yunianti, R., S. Sastrosumarjo, S. Sujiprihati, M. Surahman and S.H. Hidayat, 2007. [Resistance of 22 pepper genotypes (*Capsicum* spp.) to *Phytophthora capsici* Leonian and their genetic diversity]. Jurnal A gronomi Indonesia, 35: 103-111, (In Indonesian).

23. Mangoendidjojo, W., 2003. Basics of Plant Breeding. Kanisius Publisher, Jakarta Indonesia.
24. Yunianti, R., S. Sastrosumarjo, S. Sujiprihati, M. Surahman and S.H. Hidayat, 2010. The selection criteria for the improvement chili varieties resistance to *Phytophthora capsici* Leonian. Jurnal Agronomi Indonesia, 38: 122-129, (In Indonesian).
25. Wirnas, D., I. Widodo, Sobir, Trikoesoemaningtyas and D. Sopandie, 2006. [Selection of agronomic characters to construct selection index on 11 soybean populations F6 generation]. Jurnal Agronomi Indonesia, 34: 19-24, (In Indonesian).
26. Haydar, A., M.A. Mandal, M.B. Ahmed, M.M. Hannan and R. Karim *et al*., 2007. Studies on genetic variability and interrelationship among the different traits in tomato (*Lycopersicon esculentum* Mill.). J. Sci. Res., 2: 139-142.
27. Ganefianti, D., A. Yulian and A. Suprapti, 2006. [Correlation and path analysis among growth, yield component and yield to fruit sedding in Chilli]. Akta Agrosia, 9: 1-6.
28. Calbo, A.G., 1990. Physiology of vacuum induced tomato fruit cracking. Revista Brasileira Fisiologia Vegetal, 2: 55-61.
29. Susila, A.D., 1995. Study of fruit cracking to improve the tomatoes (*Lycopersicon esculentum* Mill. L) quality. Ph.D. Thesis, Institut Pertanian Bogor, Bogor, Indonesia.
30. Wahyuni, S., R. Yunianti, M. Syukur, J.R. Witono and S.I. Aisyah, 2014. [Resistance of 25 tomato genotypes (*Solanum lycopersicum* Mill.) to fruit cracking and its correlations to others characters]. Jurnal Agronomi Indonesia 42: 195-202, (In Indonesian).
31. Sing, R.K. and B.D. Chaudhary, 1979. Line Tester Analysis Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, India.
32. Lestari, A., W. Dewi, W. Qosim, M. Rahardja, N. Rostini and R. Setiamihardja, 2006. [Genetic variability and heritability of character of yield component and yield of fifteen red chili genotype]. Zuriat, 17: 94-102.
33. Tenaya, I.N., R. Setiamihardja, A. Baihaki and S. Natasasmita, 2003. [Heritability and gene action of fructose content, the content of capsaicin and peroxidase enzyme activity in the result of crosses between species of red pepper chili x red chili]. Zuriat, 14: 26-34.
34. Hadiati, S., H. Murdaningsih, A. Baihaki and N. Rostini, 2003. [Genetic parameters component of fruit characters in some pineapple accession]. Zuriat, 14: 53-58.
35. Sudarmadji, R. Mardjono and H. Sudarmo, 2007. [Genetic variations, heritability and genotypic correlations of important characteristics of sesame (*Sesamum indicum* L.)]. Jurnal Littri, 13: 88-92, (In Indonesian).
36. El-Gabry, M.A.H., T.I.H. Solieman and A.I.A. Abido, 2014. Combining ability and heritability of some tomato (*Solanum lycopersicum* L.) cultivars. Scientia Horticulturae, 167: 153-157.
37. Li, Y., T. Li and D. Wang, 2007. Studies on the inheritance of locule formation in tomatoes (*Lycopersicon esculentum* Mill.). J. Genet. Genom., 34: 1028-1036.
38. Hanson, P.M., J.T. Chen and G. Kuo, 2002. Gene action and heritability of high-temperature fruit set in tomato line CL5915. HortScience, 37: 172-175.
39. Roy, D., 2000. Plant Breeding: Analysis and Exploitation of Variation. Alpha Science International, USA., ISBN: 9781842650066, Pages: 701.
40. Klug, W.S., M.R. Cummings, C.A. Spencer and M.A. Palladino, 2011. Conceps of Genetics. 10th Edn., Pearson, California, San Francisco, ISBN: 9780321795779.
41. Sobir and M. Syukur, 2015. Plant Genetic. IPB Press, Jakarta, Indonesia.