Ilmu Pertanian (Agricultural Science)
http://journal.ugm.ac.id/jip
Vol. 9 No. 1 April, 2024: 1–8 | DOI: doi.org/10.22146/ipas.82772

Variability of fruit shelf-life of commercial tomatoes and their hybrids crossing with insensitivity ethylene mutant tomato *Sletr1-2*

Gungun Wiguna[1], Nedya Putri Bachtiar[2], Anas[3], Noladhi Wicaksana[3], Syariful Mubarok[3], and Imas Rita Saadah[1]*

[1]Research Center for Horticultural and Estate Crops, Research Organization of Agriculture and Food, National Research and Innovation Agency (BRIN)
Jl. Raya Jakarta – Bogor, Cibinong, Kabupaten Bogor 16915, Indonesia
[2]Graduates of the Department of Crop Science, Faculty of Agriculture, Universitas Padjadjaran
Jl. Raya Bandung – Sumedang KM 21, Jatinangor, Kabupaten Bandung 45363, Indonesia
[3]Department of Crop Science, Faculty of Agriculture, Universitas Padjadjaran
Jl. Raya Bandung – Sumedang KM 21, Jatinangor, Kabupaten Sumedang 45363, Indonesia
*Corresponding author: imas005@brin.go.id

Article Info

Received : 3rd March 2023
Revised : 14th July 2023
Accepted: 10th January 2024

Keywords:
Fruit ripening, genetic, phenotypes, shelf-life, *Sletr1-2*

Abstract

Tomatoes are climacteric fruits that experience a surge in respiration rate and ethylene production. This condition affects the fruits' physiological deterioration, shortens their shelf-life, and degrades the quality of tomatoes. The study aimed to enhance the shelf-life of commercial tomatoes with different genetic backgrounds by utilizing the *Sletr1-2* mutant, which has a lower sensitivity to ethylene. A randomized block design (RBD) was applied to achieve this goal, where 12 different plant genotypes were considered as treatments, and each treatment was replicated four times. The results showed that fruit shelf-life was extended by crossing commercial tomatoes with *Sletr1-2* mutant tomatoes. Genetic variability for all shelf-life characteristics were narrow. In contrast, there were broad phenotypic variability for fruit hardness and weight loss characteristics.

INTRODUCTION

Tomatoes are climacteric fruits, meaning that during the ripening process, there is a surge in respiration rate (Paul and Pandey, 2014; Colombié et al., 2017) and ethylene production (Liu et al., 2015; Li et al., 2020; Iqbal et al., 2017). Increased respiration rate can impact physiological damage where aging or decay occurs, decreasing shelf-life and maturation. At the same time, increasing ethylene affects its nutrient content and can accelerate fruit ripening. Both processes also impact tomatoes' quality during storage (Wicaksana, Wijaya, and Soeparjono, 2019).

Additionally, the biochemical and physiological changes during the ripening process will cause changes in the fruit's taste, color, flavor, and texture (Wang et al., 2018; Quinet et al., 2019), thereby reducing its quality. Short shelf-life in open or unpacked conditions is also one of the causes of the low quality of tomatoes. Therefore, proper handling to suppress the rate of respiration and ethylene needs to be done to extend shelf-life and produce quality tomatoes (Deepika and Rex, 2020; Pholoma, 2020).

The Indonesian Vegetable Research Institute has released several high-yielding tomato varieties that have become popular for public consumption, such as Intan, Mirah, Ratna, and Mutiara varieties. Even though these four varieties are superior and widely used by farmers, they have disadvantages because of their short shelf-life. Tomato fruit has a short shelf-life of 1 to 2 weeks after harvest. In some commercially advanced varieties released and circulated in Indonesia, the most extended shelf-life of fruit at room temperature may be up to 20 days, with a mean

How to cite: Wiguna, G., Bachtiar, N.P., Anas, Wicaksana, N., Mubarok, S., and Saadah, I.R. (2024). Variability of fruit shelf-life of commercial tomatoes and their hybrids crossing with insensitivity ethylene mutant tomato *Sletr1-2*. *Ilmu Pertanian (Agricultural Science)*, 9(1), pp. 1–8.

ISSN 0126-4214 (print) ISSN 2527-7162 (online)

of about seven days (Wicaksana et al., 2019). Even in a single hybrid variety, the shelf-life is only eight days (Rachma, 2013). The short shelf-life of tomatoes is because, since harvest, tomatoes will continue to undergo physiological processes that result in several important biochemical reactions, such as changes in metabolites, color, texture, and taste (Amin et al., 2012). This reaction results in a decrease in both the quantity and quality of fruit. Due to these issues, it is necessary to improve commercial tomato varieties to prolong their shelf-life and preserve the quality of the fruit, one of which is through breeding programs.

Breeding programs that can be carried out are hybridization techniques to combine the good qualities derived from two or more parents to obtain superior offspring (Sharma et al., 2019). The existence of crosses with genetic backgrounds of different parents can produce diverse offspring. Several researches have been done to generate tomatoes with a long shelf-life resulting from mutation (Casals et al., 2012; Yogendra and Gowda, 2013). However, many studies have also reported that tomato varieties from mutations or mutant tomatoes are generally less tasty than local varieties. An example of a mutant tomato is *Sletr1-2* tomatoes produced from the Micro-Tom library, which can delay the normal ripening process (Okabe et al., 2012) and decrease the susceptibility to ethylene (Mubarok et al., 2019). *Sletr1-1* along with *Sletr1-2*, are the novel mutant alleles which are isolated from an ethylene receptor gene, *Solanum lycopersicum* ETHYLENE RESPONSE 1 (*SlETR1*), taken from a Micro-Tom Library mutant population (Okabe et al., 2011).

The appearance of a plant is the result from interactions between plant genotypes and the environment in which they grow. Crowder (1993) states that appearance can be different or change due to the interaction between one gene and another. The four genotypes used, namely Intan, Mirah, Ratna, and Mutiara, have different genetic backgrounds. The Intan tomato was resulted from a cross between Nagcarlan and Anahu (introduced by AVRDC Taiwan). The Mirah variety was generated from Malang (tomatoes PB). Ratna was resulted from a cross between Nagcarlan and Anahu (introduction from BPI Philippines). Meanwhile, Mutiara tomato was generated from a cross between Monaibo and Venus. Since genetic background plays a crucial role in determining the appearance of tomatoes, this study aimed to investigate the variability in the formation of commercial tomatoes and their F1 hybrids resulting from crosses with *Sletr1-2* mutant tomatoes. Information on alteration and variability in fruit shelf-life characteristics due to the introduction of the *Sletr1-2* mutant is currently lacking in Indonesia. Meanwhile, this is needed as very valuable and helpful information for future tomato breeding programs.

MATERIALS AND METHODS

The equipment used in this study includes calipers, ruler, digital scales, erlenmeyer, magnetic stirrer, pH meter, spectrophotometer, penetrometer, refractometer, measuring cup, pipette, test tube, volumetric flask, color chart, and knife. Meanwhile, the materials used in this study were four commercial parents (Intan, Mirah Ratna, and Mutiara) and 8 F1 plants as progeny between commercial tomato varieties as female parents and tomato mutants (*Sletr1-2* and wild-type) as male parents. Other materials used are distilled water, 1% indicator Phenolphthalein (PP), and 0.1N NaOH.

The experimental design used was a randomized block design (RBD) with a factor in genotype (G). The experiment consisted of 12 treatments, each with four replications. The effect of each treatment was analyzed using Analysis of Variance (ANOVA). Data showing significant differents between treatments were then analyzed using the Scott-Knott post-hoc

Table 1. Main fruit characteristics of four commercial tomatoes

Genotype	Fruit shape	Number of locules	Weight per fruit (g)	Fruit length (cm)	Fruit diameter (cm)	Pericarp thickness (cm)
Intan	Oblong	3 – 9	40 – 65	3.2 – 4.9	3.8 – 5.0	0.3 – 0.4
Mirah	Oblate	3 – 7	20 – 40	2.1 – 4.1	3.0 – 4.0	0.2 – 0.3
Ratna	Oblong	4 – 8	45 – 85	3.5 – 5.7	5.0 – 6.0	0.3 – 0.4
Mutiara	Oval	3 – 6	35 – 50	3.0 – 4.4	3.5 – 4.5	0.3 – 0.5

Remarks: The data are summarized from variety descriptions (Anas et al., 2022).

comparison.

Genetic variability (σ^2g) and phenotypic variablity (σ^2f) can be obtained based on the analysis of variance. Determination of criteria for genetic and phenotypic variability is done by comparing genetic and phenotypic variance with standard deviation. An observed character has a broad genetic variability value if the value is equal to or twice the genetic standard deviation ($\sigma^2g \geq 2\sigma_{\sigma^2g}$). The same applies to phenotypic variability. Phenotypic variability is broad if the phenotype values are the same or greater than twice the standard deviation ($\sigma^2f \geq 2\sigma_{\sigma^2f}$). The standard deviation of genetic variance and phenotype is assumed by the following formulas (Anderson and Bancroft, 1952):

$$\sigma_{\sigma_g^2} = \sqrt{\frac{2}{r^2}\left[\left(\frac{MSg^2}{df_g+2}\right) + \left(\frac{MSe^2}{df_e t+2}\right)\right]} \quad \text{.....(1)}$$

$$\sigma_{\sigma_f^2} = \sqrt{\frac{2}{r^2}\left(\frac{MSg^2}{df_g+2}\right)} \quad \text{.....(2)}$$

Remarks:

σ_{σ^2g} = standard deviation of genetic variance
σ_{σ^2f} = standard deviation of the phenotypic variance
MSg = genetic mean square
MSe = error mean square
df_g = genetic degrees of freedom
r = replication

The experiment was carried out using tomatoes planted in the Indonesian Vegetable Research Institute Experimental Field at an altitude of 1,250 m asl with andosol soil types. Planting was done in an area of 100 m². Tomato plants were grown on land with genotype as factor consisting of 12 treatments and four replications. Each replication in one treatment consisted of five plants, resulting in a total of 240 experimental units.

Yields from planting were used as testing samples. The fruit was harvested when the maturation stage is Br+6 (Mubarok et al., 2015) to determine the character of the shelf-life of each treatment. Character analysis was carried out at the Physiology of Postharvest Laboratory, the Indonesian Vegetable Research Institute, Lembang. Observations were made by observing and analyzing the character of the storability of tomatoes for a shelf-life of 0 days, a shelf-life of 10 days, and a shelf-life of 20 days. The sampling method for one replication in one genotype was by combining the yields in each replication, and then ten pieces were taken for the needs of the entire quality analysis. The treatment in one observation was repeated three times.

Determining long shelf-life involved monitoring the fruit from the start of storage until its quality deteriorates, indicated by the emergence of black spots or wrinkles on the fruit surface. Measurement of fruit hardness was done using a penetrometer. The sample used in each genotype is four pieces to get ten stabbing times. The way to do this is to put tomatoes just below the penetrometer piercing needle. The tomatoes were stabbed at three points on their surface (tip, middle, and base), and the duration required to exert maximum pressure on the tomatoes was measured using a stopwatch for 10 seconds. A ballast with a weight of 50 grams was used during the test. The calculation results were the average numbers obtained from the measurements. The units used are millimeters (mm) per 10 seconds with a specific load weight expressed in grams or mm/second/gram.

Weight loss during storage was measured on the ten days post storage (DPS) and 20 DPS during storage by weighing tomatoes. The level of water loss indicates the weight loss from tomatoes during the storage period because only the water can evaporate during the storage process. The formula used is as follows:

$$Loss\ of\ water = \frac{(a-b)}{a} \times 100\% \quad \text{.....(3)}$$

Remarks:

a = weight before storage or initial weight
b = weight after being stored

RESULTS AND DISCUSSION

Fruit freshness

The analysis results showed that Intan, Mirah, Ratna, and Mutiara's four commercial parents have a shorter shelf-life than the tomatoes from crossing with the *Sletr1-2* mutant (Figure 1). This result is in accordance with Afifah et al. (2021), comparing some commercial tomato varieties, including Intan and Ratna varieties, with a mutant breeding line, where this line showed a better performance in shelf-life. According to the findings, Intan x *Slert1-2* hybrids have the longest average shelf-life (35 days), while Mirah, Ratna, and Mutiara hybrids have the shortest average shelf lives (12, 14, and 13 days, respectively). The results of crosses between commercial tomatoes and mutant *Sletr1-2* tomatoes differ from the commercial parents.

This result shows that the *Sletr1-2* mutant allele influences the shelf-life of the crosses from tomatoes. The effect given by the mutant allele on tomatoes from crosses is a positive influence that can increase the shelf-life of tomatoes. Hiwasa-Tanase (2016) states that *Sletr1-2* can extend tomatoes' fruit shelf-life. *Sletr1-2* can maintain fruit surface intact even 60 days after harvest. The ability of mutant alleles to increase shelf-life is due to the *SlETR1* gene mutation, which can inhibit the normal ripening process in the fruit because it can reduce sensitivity to ethylene (Mubarok et al., 2015).

Fruit hardness

Loss of fruit hardness is one of the significant changes during fruit ripening (Ghaiet al., 2016). The hardness of fruit between commercial tomatoes and the results of their crosses is generally in a different average group. The results indicated significant differences between the two groups. Nevertheless, at 0 DPS, Mirah x *Sletr1-2*, at 10 DPS and 20 DPS, Intan x *Sletr1-2*, and at 20 DPS, Mutiara x *Slert1-2*, exhibited fruit hardness levels that were comparable to their commercial parents. However, the hardness values tended to be slightly lower (Table 2). The lower hardness value suggests that the fruit texture is firmer.

In the fruit from the cross between commercial tomatoes and *Sletr1-2* mutants, the fruit hardness is more potent than commercial tomatoes. The fruit firmness of commercial tomatoes is softer than that of tomatoes crossed with the *Sletr1-2* mutant, probably due to a higher respiration rate. It is well known that

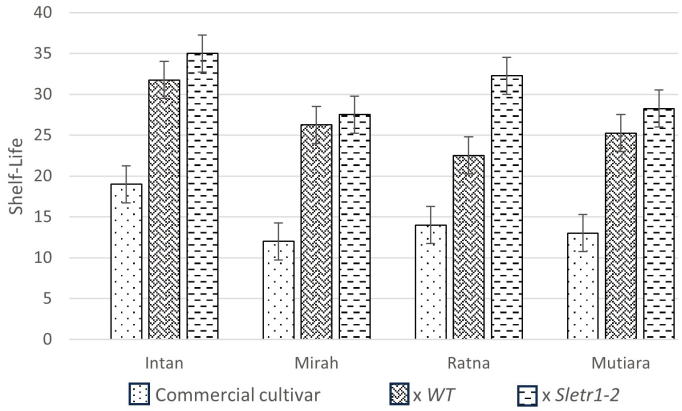

Figure 1. The freshness of the fruit of four commercial tomato cultivars and the results of the crossing with tomatoes WT and *Sletr1-2* mutants

Table 2. The Scott-Knott test results on fruit hardness of 12 tomato genotypes

Genotype	Fruit hardness (mm/10 sec/50 g)					
	0 DPS		10 DPS		20 DPS	
Intan	17.09	a	17.34	b	17.43	b
Intan x WT	16.99	a	17.32	b	17.97	b
Intan x *Sletr1-2*	15.35	b	15.90	b	16.65	b
Mirah	17.76	a	18.42	a	19.29	a
Mirah x WT	17.78	a	17.92	a	17.99	b
Mirah x *Sletr1-2*	16.74	a	16.96	b	17.24	b
Ratna	17.28	a	18.42	a	20.40	a
Ratna x WT	16.74	a	18.38	a	20.02	a
Ratna x *Sletr1-2*	14.36	b	16.32	b	18.56	b
Mutiara	16.95	a	17.46	b	19.11	a
Mutiara x WT	15.81	b	17.33	b	18.61	b
Mutiara x *Sletr1-2*	15.74	b	17.01	b	18.03	b

Remarks: Means followed by the same lowercase letters in the same column are not significantly different based on the Scott-Knott test at the level of α=5 %.

respiration can reorganize carbohydrate polymers in cell walls, particularly pectin and cellulose. As a result, the wall strength and bonding cohesion may decrease, softening the texture of the fruit (Wills et al., 1981). Crosses between commercial tomatoes and *Sletr1-2* mutants in tomatoes can prevent cell wall breakdown. The *SlETR1* gene mutation found in these crosses decreases ethylene sensitivity, avoiding the respiration rate that initiates the process. This state is in line with the research of Sholiha (2018), reporting that the treatment of 1-MCP concentrations of 30.625 mg/100 ml showed a maturity level of 1, which describes the textures of the fruit in harsh conditions.

Fruit weight loss

Regarding weight loss, commercial tomatoes and their progeny results are generally in the same average group. The findings indicated that the *Sletr1-2* mutant allele on crossed tomatoes had no significant effect. However, there was a significant effect on weight loss

Table 3. The Scott-Knott test results on fruit weight loss of 12 tomato genotypes

Genotype	Weight loss (%)	
	0 DPS	20 DPS
Intan	4.28 b	4.15 b
Intan x WT	5.31 a	6.85 a
Intan x *Sletr1-2*	4.33 b	4.88 b
Mirah	4.18 b	6.68 a
Mirah x WT	4.20 b	6.57 a
Mirah x *Sletr1-2*	4.42 b	5.03 b
Ratna	3.90 b	5.17 b
Ratna x WT	6.03 a	7.17 a
Ratna x *Sletr1-2*	5.29 a	6.93 a
Mutiara	4.03 b	7.95 a
Mutiara x WT	3.87 b	6.67 a
Mutiara x *Sletr1-2*	4.06 b	7.72 a

Remarks: Means followed by the same lowercase letters in the same column are not significantly different based on the Scott-Knott test at the level of α=5 %.

Table 4. The genetic variability values of the character of the storability of 12 tomato genotypes

Character	Days after storage	Genetic variability		
		σ^2g	$2\sigma_{\sigma^2g}$	Gloss
Fruit freshness	1–36	61.340	96.730	narrow
Fruit hardness	0	0.803	1.267	narrow
	10	0.450	0.777	narrow
	20	1.051	1.491	narrow
Fruit weight loss	10	0.325	0.720	narrow
	20	1.271	1.674	narrow

Table 5. The phenotypic variability values of the character of the storability of 12 tomato genotypes

Character	Days after storage	Phenotype variability		
		σ^2g	$2\sigma_{\sigma^2g}$	Gloss
Fruit freshness	1–36	62.593	96.729	narrow
Fruit hardness	0	1.574	1.247	broad
	10	1.034	0.758	broad
	20	1.672	1.480	broad
Fruit weight loss	10	0.833	0.709	broad
	20	1.714	1.670	broad

for Ratna x *Sletr1-2* at 10 DPS and Mirah x *Sletr1-2* at 20 DPS (Table 3). The increase in weight loss in tomatoes resulted from crossing with the *Sletr1-2* mutant allele is thought to be because the effect of the mutation on the *SlETR1* gene has been lost. As a result, it cannot inhibit ethylene sensitivity.

According to Okabe et al. (2012), mutations in *SlETR1* (*Solanum lycopersicum* ETHYLENE RESPONSE 1) produce *Sletr1-1* and *Sletr1-2* mutants that experience inhibition of gene activity as indicated by an unresponsive reaction to exogenous ethylene to a concentration of 10 ppm. The disappearance of the effect of the *SlETR1* gene causes the process of respiration and transpiration in the fruit to function normally, so the weight loss that occurs can be equal to or greater than the commercial parent.

Variability of shelf-life appearance

The value of genetic variability for all observed characters is narrow (Table 4). This result indicates that the tested plant population tends to be homogenous. Furthermore, it should be noted that the sampled population is the F1 generation, which does not undergo segregation. This limited genetic variability must be enhanced to succeed in breeding programs. As highlighted by Poehlman and Sleper (1995), plants cannot be improved without genetic variation. Genetic recombination can increase genetic variability, and one approach is crossing with distant relatives. Additionally, Crowder (1993) suggested that plants in the F2 generation exhibit high variability due to segregation under Mendel's law.

The variation in phenotype for fruit freshness is narrow (Table 5), which suggests that only some individuals can be chosen. Conversely, the characteristics of fruit hardness and weight loss display a broad phenotypic variability. Austiet al. (2014) indicated that the broad phenotypic variability could be attributed to extensive environmental variations. Furthermore, plant varieties grown under the same conditions may exhibit distinct phenotypic responses.

According to Murti et al. (2002), different genotypes have different abilities in absorbing nutrients even though the environment used is relatively the same, so it can cause a variety of phenotypic appearances from each genotype planted. The high and low variability of the phenotype illustrates the appearance of genotypes tested in the field.

CONCLUSIONS

All hybrid *Sletr1-2* mutants have a more excellent freshness than their commercial parents. Intan x *Sletr1-2* shows the best shelf-life, with a shelf-life of 35 days. All characters show narrow genetic variability. The broad variability of phenotypes is found in the character of fruit hardness and fruit weight loss.

ACKNOWLEDGEMENTS

The authors are grateful to the Tsukuba Plant Innovation Research Center, the University of Tsukuba, for providing the wild-type 'Micro-Tom' (WT - MT) and mutant line. This work was supported by a research grant from the Ministry of Education and Culture, Republic of Indonesia. The author gratefully acknowledges the Ministry of Agriculture, Republic of Indonesia, for education scholarship at Universitas Padjadjaran.

REFERENCES

Afifah, E.N., Murti, R.H., and Wahyudhi, A. (2021). Evaluation of a promising tomato line (*Solanum lycopersicum*) derived from muta*tion breeding. Biodiversitas Journal of Biological Diversity*, 22(4), pp. 1863–1868.

Amin, A., Wani, K.P., Mir, H., Khan, S.H., Mushtaq, F., Kumar, P., Afroza, B., and Samad, S.S. (2012). Combining Ability Analysis for Yield and Its Attributing Traits over Environments in Tomato (*Solanum lycopersicum* L.). *Journal of Agricultural Science*, 4(11), pp. 276–280.

Anas, A., Wiguna, G., Damayanti, F., Mubarok, S., Setyorini, D., and Ezura, H. (2022). Effect of Ethylene Sletr1-2 Receptor Allele on Flowering, Fruit Phenotype, Yield, and Shelf-Life of Four F1 Generations of Tropical Tomatoes (*Solanum lycopersicum* L.). *Horticulturae*, 8(12), pp. 1098.

Austi, I.R., Damanhuri, and Kuswanto (2014). Keragaman Dan Kekerabatan Pada Proses Penggaluran Kacang Bogor (*Vigna subterranea* L . Verdcourt) Jenis Lokal. *Produksi Tanaman*, 2(1), pp. 73–79.

Casals, J., Pascual, L., Cañizares, J., Cebolla-Cornejo, J., Casañas, F., and Nuez, F. (2012). Genetic basis of long shelf life and variability into Penjar tomato. *Genetic Resources and Crop Evolution*,

59(2), pp. 219–229.

Colombié, S., Beauvoit, B., Nazaret, C., Bénard, C., Vercambre, G., Le Gall, S., Biais, B., Cabasson, C., Maucourt, M., Bernillon, S., Moing, A., Dieuaide-Noubhani, M., Mazat, J., and Gibon, Y. (2017). Respiration climacteric in tomato fruits elucidated by constraint-based modelling. *New Phytologist*, 213(4), pp. 1726–1739.

Crowder, L.V. (1993). *Plant Genetics (Genetika Tumbuhan alih bahasa L. Kusdiarti dan Soetarso)*. Yogyakarta: Gadjah Mada University Press, 499p.

Deepika, V., and Rex, B. (2020). Technology to enhance post harvest shelf life of horticultural crops. *Biotica Research Today*, 2(5 Spl.), pp. 281–282.

Ghai, K., Gupta, P.K., and Gupta, A.K. (2016). Physiochemical behaviour changes during ripening in fruits of Trewia nudiflora Linn. *Perspectives in Science*, 8, pp. 596–598.

Hiwasa-Tanase, K. (2016). Fruit Ripening in Tomato and Its Modification by Molecular Breeding Techniques. In: *Functional Genomics and Biotechnology in Solanaceae and Cucurbitaceae Crops*. Springer, pp. 155–174.

Iqbal, N., Khan, N.A., Ferrante, A., Trivellini, A., Francini, A., and Khan, M.I.R.R. (2017). Ethylene Role in Plant Growth, Development and Senescence: Interaction with Other Phytohormones. *Frontiers in Plant Science*, 08(April), pp. 1–19.

Li, S., Zhu, B., Pirrello, J., Xu, C., Zhang, B., Bouzayen, M., Chen, K., and Grierson, D. (2020). Roles of RIN and ethylene in tomato fruit ripening and ripening-associated traits. *New Phytologist*, 226(2), pp. 460–475.

Liu, M., Pirrello, J., Chervin, C., Roustan, J.P., and Bouzayen, M. (2015). Ethylene control of fruit ripening: Revisiting the complex network of transcriptional regulation. *Plant Physiology*, 169(4), pp. 2380–2390.

Mubarok, S., Ezura, H., Anas, Kusumiyati, Rostini, N., Suminar, E., and Wiguna, G. (2019). Impacts of Sletr1-1 and Sletr1-2 mutations on the hybrid seed quality of tomatoes. *Journal of Integrative Agriculture*, 18(5), pp. 1170–1176.

Mubarok, S., Okabe, Y., Fukuda, N., Ariizumi, T., and Ezura, H. (2015). Potential Use of a Weak Ethylene Receptor Mutant, Sletr1-2 , as Breeding Material To Extend Fruit Shelf Life of Tomato. *Journal of Agricultural and Food Chemistry*, 63(36), pp. 7995–8007.

Murti, R.H., Prajitno, D., Aziz, P., and Tamrin (2002). Keragaman genotip salak lokal sleman. *J. Habitat*, XIII(1), pp. 1–7.

Okabe, Y., Asamizu, E., Ariizumi, T., Shirasawa, K., Tabata, S., and Ezura, H. (2012). Availability of Micro-Tom mutant library combined with TILLING in molecular breeding of tomato fruit shelf-life. *Breeding Science*, 62(2), pp. 202–208.

Okabe, Y., Asamizu, E., Saito, T., Matsukura, C., Ariizumi, T., Brès, C., Rothan, C., Mizoguchi, T., and Ezura, H. (2011). Tomato TILLING Technology: Development of a Reverse Genetics Tool for the Efficient Isolation of Mutants from Micro-Tom Mutant Libraries. *Plant and Cell Physiology*, 52(11), pp. 1994–2005.

Paul, V., and Pandey, R. (2014). Role of internal atmosphere on fruit ripening and storability - A review. *Journal of Food Science and Technology*, 51(7), pp. 1223–1250.

Pholoma, S.B. (2020). Is Ethylene the Ripening Hormone. *Journal of Experimental Agriculture International*, 42(5), pp. 1–7.

Poehlman, J.M. and Sleper, D.A. (1995). Breeding field crops. Iowa State University Press, Ames, IA. *Breeding field crops*. 4th ed. Iowa State Univ. Press, Ames, IA.

Quinet, M., Angosto, T., Yuste-Lisbona, F.J., Blanchard-Gros, R., Bigot, S., Martinez, J.-P., and Lutts, S. (2019). Tomato Fruit Development and Metabolism. *Frontiers in Plant Science*, 10(November), pp. 1–23.

Rachma, N.V. (2013). *Deskripsi Tomat Varietas Servo*. Indonesia

Sharma, P., Thakur, S., and Negi, R. (2019). Recent Advances in Breeding of Tomato- A Review. *International Journal of Current Microbiology and Applied Sciences*, 8(03), pp. 1275–1283.

Sholiha, R.P. (2018). *Pengaruh 1-methylcyclopropene (1-MCP) dan tingkat kematangan terhadap masa simpan dan beberapa komponen kualitas buah tomat (Lycopersicum Zsculentum Mill.)*. Doctoral dissertation. Mataram: Universitas Mataram.

Wang, L., Luo, W., Sun, X., and Qian, C. (2018). Changes in flavor-relevant compounds during vine ripening of tomato fruit and their relationship with ethylene production. *Horticulture, Environment, and Biotechnology*, 59(6), pp. 787–804.

Wicaksana, P.C., Wijaya, K.A., and Soeparjono, S. (2019). The Role of Potassium and Calsium in Improving The Quality and Shelf Life of Tomato

(*Lycopersicum esculentum* var. servo). *El-Hayah*, 7(2), pp. 84–93.

Wills, R.H.H., Lee, T.H., Graham, D., McGlasson, W.B., and Hall, E.G. (1981). *Postharvest. An introduction to the physiology and handling of fruit and vegetables*. Granada.

Yogendra, K.N.N., and Ramanjini Gowda, P.H.H. (2013). Phenotypic and molecular characterization of a tomato (*Solanum lycopersicum* L.) F2 population segregation for improving shelf life. *Genetics and Molecular Research*, 12(1), pp. 506–518.