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Research Article

Fruit quality and shelf-life improvement of tomato (*Solanum lycopersicum* L.) 'Servo' by inorganic fertilizer enriched with amino acid

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ABSTRACT

Fertilizer and maturity stage affect the nutritional content and quality of tomatoes. This study aimed to obtain the best dosage of amino acid fertilizer on the qualities and shelf life and to determine the effect of the maturity stage on the qualities of Servo tomatoes. The research design used factorial RCBD with 3 blocks as replications. The Servo tomatoes were grown in Wonosobo District and foliar fertilized with 4 levels of amino acid fertilizer, namely 0, 1, 2, and 4 L ha^{-1} amino acid fertilizer, and 2 L ha^{-1} comparison fertilizer. Observation of tomato fruit quality was conducted in Horticulture Sublaboratory, UGM at 27,5 °C with relative humidity of 73%. The quality observed was CO_2 concentration, visual quality rating, weight loss, fruit firmness, fruit color, TSS, TTA, carotenoids, lycopene, flavonoids, and vitamin C. The observation was terminated when the score of VQR reached 3 as shelf life of tomatoes. Amino acid fertilizer can improve the quality of Servo tomatoes as seen from the parameters of fruit color (a) and total titrated acid (TTA). In terms of other parameters, the amino acid fertilizer does not affect the quality of Servo tomatoes. The highest value on fruit color (a*) and TTA resulted from 2 L ha^{-1} of amino acid fertilizer. The maturity stage significantly affects the quality improvement of fruit firmness, weight loss, VQR, CO_2 concentration, TTA, total soluble solids, carotenoids, and flavonoids. The addition of 4 L ha^{-1} amino acid fertilizer was insignificantly able to increase the commercial shelf life of tomatoes for 4 days compared to the control.*

Keywords: Aminoalkanoic; fertilizer effect; storage life; tomato quality

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INTRODUCTION

The tomato plant (*Solanum lycopersicum* L.) is a self-pollinating annual plant belonging to the Solanaceae family. Tomato plants produce tomatoes that come in a variety of shapes and sizes, depending on the variety. In Indonesia, the characteristics of tomatoes that people like tend to be rather large in size with a slightly oval shape, red skin, and sweet taste. One of the tomato varieties that is widely marketed and consumed by Indonesian is Servo. Servo tomatoes are popular because they are resistant to viruses so they are not easily damaged during post-harvest handling to distribution (Fadhila, 2020). Based on Merah (2022), the productivity of Servo tomato plants is relatively high, ranging from 31 to 53 fruits per plant, with round fruit shapes, green shoulders, and a rather hard texture. Although Servo tomatoes have a fairly firm texture and are classified as not easily damaged, it should also be noted that tomatoes are classified as perishable climacteric and horticultural fruits. This causes tomatoes to have a short shelf life and quickly experience

a decrease in quality which has an impact on the economic value of the product. The quality of tomatoes depends on the nutritional content which is influenced by the fruit maturity phase (Duma et al., 2015). In an effort to optimize the quality and nutritional content of tomatoes, one thing that can be done is to determine changes in the chemical content of tomatoes in each stage of maturity.

Meanwhile, the quality and economic value of tomatoes are identical to the physiological conditions and quality of the product. One of the factors that affect the quality of tomatoes is the intake of nutrients during the formation and ripening of tomatoes. Nutrient intake is obtained from nutrients available in the environment around the plant. Nutrients in a plant environment can be modified by adding fertilizer. Fertilizers contain nutrients for plants that play an important role in plant growth and metabolism to form important compounds, one of which is amino acids. Amino acids include plant biostimulants which act as biologically active substances to encourage plant growth and increase plant resistance in facing environmental stress (Shangqiang et al., 2019). Calvo (2019) revealed that the impact obtained by plants after the application of amino acid fertilizers is to increase the modulation of absorption and assimilation of elemental N so that it can improve the yield and quality of horticultural products. In addition, the amino acid content also has an impact on the fruit produced, namely increasing the formation of pectin between the cell wall and the middle lamella so that the texture of the fruit becomes harder (Shin et al., 2021).

Research about the effect of amino acids on the quality of tomatoes is rarely done in Indonesia. However, several previous studies regarding the effect of amino acid applications on the growth and quality of tomato fruit have been carried out by Salim et al. (2021) located in Egypt, Ahmed & Almohammedi (2021) located in Iraq, and Wang et al. (2021) located in Spain. The addition of amino acids can increase the content of chlorophyll, carotenoids, and total dissolved protein (Salim et al., 2021). The addition of the amino acid arginine 1 mmol L^{-1} can increase the content of lycopene, vitamin C, total soluble solids (TSS), organic acids, and the ratio of sugar and acid (Wang et al., 2021). Meanwhile, the addition of 300 mg L^{-1} of arginine was able to increase the content of vitamin C and lycopene in cherry tomatoes (Ahmed & Almohammedi, 2021). Amino acid fertilizer that was used in this experiment contains 6.5% of N, 2% of P_2O_5, 1.5% of K_2O, 10% of amino acid, and each 0.1% of B and Mn. Therefore, this research was conducted to determine the effect of amino acid fertilizer application on improving the quality and storability of Servo variety and to determine the effect of the maturity stage on the quality of Servo tomatoes.

MATERIALS AND METHODS

Servo tomatoes were planted in Wonosobo District, Central Java in June-September 2022. The altitude of the area is around 1,100-1,200 m. The experimental design in planting used a randomized complete block design with 3 blocks as replications. Quality and shelf life tests were carried out in September-November 2022 at the Horticulture Sublaboratory, Faculty of Agriculture, Gadjah Mada University. Amino acid fertilizer produced by PT Cheil Jedang contained 6.5% of N, 2% of P_2O_5, 1.5% of K_2O, 10% of amino acid, and each 0.1% of B and Mn. Meanwhile, the comparison fertilizer contained 10% of N, 2% of K_2O, 2% of P_2O_5, each 0.25% of Zn, Mn, Cu, and Mo, 0.125% of B, 0.0005% of Co, 5% of organic C, and 1% of Biuret.

Treatment consisted of 5 levels, namely amino acid fertilizer (0 L ha^{-1}), comparison fertilizer (2 L ha^{-1}), amino acid fertilizer (1 L ha^{-1}), amino acid fertilizer (2 L ha^{-1}), and amino acid fertilizer (4 L ha^{-1}). Fertilizer application was carried out at 3, 2, and 1 week before harvest, specifically at the age of seedlings 41, 48, and 55 days after planting (DAP). The fertilizer was sprayed to foliar. Each plot of land required 1.82 ml, 3.64 ml, and 7.28 ml of fertilizer diluted in 910 mL of water for the amino acid fertilizer treatment of 1 L ha^{-1}, 2 L ha^{-1}, and 4 L ha^{-1}. The tomatoes used in this study were harvested at 79 days after planting (DAP) when the tomatoes reached turning stage. The harvested tomatoes were then put into clean plastic bags and perforated to be taken to the laboratory. Furthermore,

sorting was carried out based on the uniformity of shape, size, color, and degree of ripeness of the tomatoes, and selected those that were free from pathogenic infection. This experiment used tomatoes in turning stage marked by the appearance of <10% red color on the surface of the tomatoes. Furthermore, 30 tomatoes were placed in 1 plastic tray measuring 36 x 27.5 x 5.5 cm, as 1 experimental unit. This experiment used 15 experimental units.

The quality observed consisted of physiological, physical, and chemical qualities. The physiological quality of tomatoes was measured from the concentration of CO_2 (%) resulting from respiration carried out in 4 stages of maturity, namely turning (4 DAH), light red (11 DAH), red (24 DAH), and senescence (38 DAH). Physical quality included weight loss, fruit firmness (Bareiss BS 61 II Durometer), Visual Quality Rating [VQR] (Kader, 1973) which were observed every three days until the VQR value of tomatoes reached 3, and fruit color (L* = fruit brightness; a* = green-red; b* = blue-orange, used a chromameter). The chemical qualities observed included total soluble solids (used a digital refractometer), total titrated acid (in %), carotenoids (Sari & Hidayati, 2020), lycopene (Adejo et al., 2015; Suwanaruang, 2016), flavonoids (Chang et al., 2002), and vitamin C. Data were analyzed by factorial ANOVA and continued with Duncan's Multiple Range Test (DMRT) at α = 5%.

RESULTS AND DISCUSSION

The evaluations in this experiment involve physiological, physical, and chemical aspects that are related to fruit quality. Based on the data analysis, there was no interaction between the doses of amino acid fertilizer and the maturity stage on the physiological, physical, and chemical quality, as well as the storability of Servo tomatoes. Therefore, the presentation of the data uses the mean separation of each factor. Each maturity stage is determined by color changes.

Table 1. Servo tomato CO_2 concentration in various treatments and stages of maturity.

Maturity stage	CO_2 concentration (%)					Mean
	AA fertilizer (0 L ha^{-1})	Comparison fertilizer (2 L ha^{-1})	AA fertilizer (1 L ha^{-1})	AA fertilizer (2 L ha^{-1})	AA fertilizer (4 L ha^{-1})	
Turning (4 DAH)	6.65	6.97	6.81	6.89	6.85	6.83a
Light red (11 DAH)	5.96	5.97	5.99	5.97	5.97	5.97b
Red (24 DAH)	6.33	6.70	6.21	6.59	6.44	6.45a
Senescence (38 DAH)	5.91	5.85	5.82	5.94	6.01	5.91b
Note			ns			*
CV (%)						8.8

Note: AA = amino acid; DAH = days after harvest; * = significant at p-value < 0.05; ns = not significant; CV = coefficient of variation; different letters between maturity stages showed significant differences based on the DMRT test at α = 0.05.

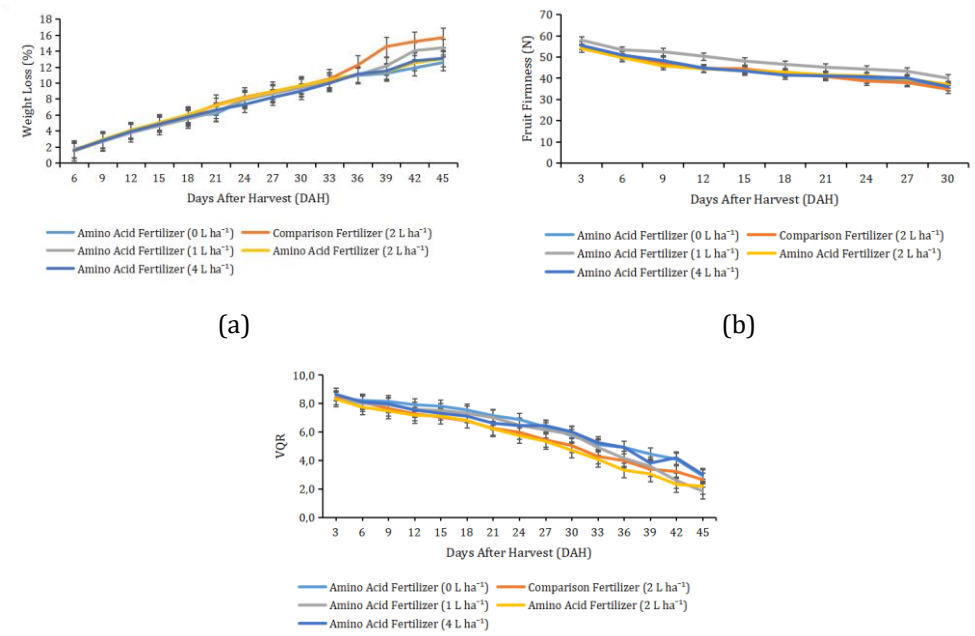
Different dosages of amino acid fertilizer did not significantly affect the CO_2 concentration resulting from the respiration of Servo tomatoes in all stages of maturity. The concentration of CO_2 produced by respiration is more influenced by several environmental factors, namely the size and arrangement of fruit tissue, the ratio of young fruit tissue, and external factors such as temperature and humidity (Wulandari & Ambarwati, 2022). Meanwhile, the ripening phase of tomatoes has a significant effect on the resulting CO_2 concentration. This is in accordance with the opinion of Saltveit et al., (2016) that the respiration rate changes in each maturity stage due to changes in fruit tissue and ethylene production that occurs with ripening. Visual changes, weight, and firmness of tomatoes occur during storage which illustrates the worsening condition of the fruit due to the appearance of wrinkles and texture softening.

Table 2. Recapitulation of variance of VQR, weight loss, and fruit firmness of Servo tomatoes in several stages of maturity.

Variable	Days after harvest	F-test	p-value	Note
Weight loss	6	0.32	0.86	ns
	12	0.22	0.92	ns
	24	0.31	0.87	ns
Fruit firmness	3	0.37	0.83	ns
	12	1.04	0.44	ns
	24	0.78	0.57	ns
VQR	3	0.61	0.67	ns
	12	1.12	0.41	ns
	24	0.70	0.61	ns
	42	5.69	0.02	*

Note: * = significant at p-value < 0.05; ns = not significant.

Different dosages of amino acid fertilizer had no significant effect on the Servo tomato weight loss and fruit firmness. Meanwhile, different dosages of amino acid fertilizer had a significant effect on the tomato Servo's VQR value at 42 DAH. This happens because the physical quality of the fruit is more influenced by the length of storage and maturity level (Marlina et al., 2014).



(a) (b)

(c)

Figure 1. (a) Tomato Servo weight loss on various fertilizer treatments, (b) Tomato Servo fruit firmness on various fertilizer treatments, and (c) Tomato Servo VQR on various fertilizer treatments.

The lowest weight loss was found in Servo tomatoes without fertilization, while the highest weight losses were found in Servo tomatoes treated with comparison fertilizer (2 L ha^{-1}). Low weight loss is the result of slow transpiration and respiration rates. Transpiration greatly affects weight loss during storage because it causes loss of water as the main constituent of tomatoes. Meanwhile, Servo tomatoes treated with comparison fertilizer (2 L ha^{-1}) had the lowest fruit firmness (34.73 N). At the end of storage, tomatoes treated with amino acid fertilizer (1 L ha^{-1}) had the highest fruit firmness (39.93 N) and lowest VQR. These results are in accordance with the research of Frías-Moreno et al.

(2020) and Zhang et al. (2020) that the firmness of tomato fruit increases with an increase in the dose of elemental N but at certain doses, it will cause a decrease in fruit firmness because the translocation of Ca^{2+} ions in the fruit cell wall is inhibited resulting in loss of integrity of the fruit cell wall.

During storage, there was a decrease in fruit firmness. Respiratory activity causes the breakdown of polysaccharides and the overhaul of cell wall compounds in the form of insoluble protopectin to soluble protopectin (Kusumiyati et al., 2018). Protopectin dissolved in the middle lamella in the cell wall causes a loss of integrity of the cell wall so that the membrane becomes more permeable and results in fruit becoming softer (Dhall & Singh, 2016). The highest VQR value at the end of storage was found in tomatoes treated with amino acid fertilizer (4 L ha^{-1}). A decrease in visual quality during storage occurs due to physical damage in the form of wrinkles and wilting as a result of loss of water and the breakdown of compounds resulting from metabolic activity (Lathifa, 2013). Different dosages of amino acid fertilizer had a significant effect on the tomato Servo's VQR value at 42 DAH. This happens because the physical quality of the fruit is more influenced by the length of storage and maturity level (Marlina et al., 2014).

Table 3. Weight loss, fruit firmness, and VQR in several maturity stages.

Maturity stage	Weight loss (%)	Fruit firmness (N)	VQR
Turning (3 DAH)	-	55.05a	8.40a
Light red (12 DAH)	3.90b	45.67b	7.49b
Red (24 DAH)	7.88a	40.77c	6.29c
Interaction	ns	ns	ns
Note	*	*	*
CV (%)	12.46	8.64	8.53

Note: DAH = days after harvest; (-) = no measurements were taken; ns = not significant; * = significant at p-value < 0.05; CV = coefficient of variation; different letters between maturity stages showed significant differences based on the DMRT test at $\alpha = 0.05$.

The maturity stage has a significant effect on weight loss, fruit firmness, and VQR (John et al., 2020). A decrease in quality can be caused by the age of the tomatoes after being harvested. The longer the age of the tomatoes after being harvested or the day after harvest (DAH), the quality of the tomatoes will decrease due to the metabolic activity that occurs. Servo tomato fruit color measurements showed in L*, a*, and b* values which are presented in Table 4.

Table 4. L*, a*, and b* values of tomatoes with various treatments.

Treatment	Mean at red stage (24 DAH)		
	L*	a*	b*
Amino acid fertilizer (0 L ha^{-1})	33.97	20.56c	14.25
Comparison fertilizer (2 L ha^{-1})	35.93	22.48a	15.72
Amino acid fertilizer (1 L ha^{-1})	34.56	21.46bc	14.89
Amino acid fertilizer (2 L ha^{-1})	34.73	21.68ab	14.82
Amino acid fertilizer (4 L ha^{-1})	35.53	21.31bc	15.37
Note	ns	*	ns
CV (%)		2.16	

Note: L* = fruit brightness; a* = green—red; b* = blue—orange; (-); * = significant at p-value < 0.05; CV = coefficient of variation; ns = not significant.

Different dosages of amino acid fertilizer had a significant effect on the a* value but had no significant effect on the L* and b* values. These results are in line with research by Carricondo-Martínez et al. (2022) that the resulting a* value is influenced by fertilizer

which has an impact on the activity of lycopene biosynthesis in producing a red color. Meanwhile, the quality of tomatoes is also influenced by chemical quality. The chemical quality content of Servo tomatoes in the five treatments during storage is presented in Table 5, Table 6, Table 7, and Table 8.

Table 5. Total soluble solids (TSS) tomato Servo on various treatments and maturity stages.

Maturity stage	Total soluble solids (°Brix)					Mean
	AA fertilizer (0 L ha^{-1})	Comparison fertilizer (2 L ha^{-1})	AA fertilizer (1 L ha^{-1})	AA fertilizer (2 L ha^{-1})	AA fertilizer (4 L ha^{-1})	
Turning (4 DAH)	3.97	4.03	4.50	3.93	4.23	4.13b
Light red (11 DAH)	4.73	4.67	5.10	4.50	4.73	4.75a
Red (24 DAH)	3.83	3.83	3.40	3.93	3.80	3.76c
Note			ns			*
CV (%)						8.5

Note: AA = amino acid; DAH = days after harvest; * = significant at p-value < 0.05; ns = not significant; CV = coefficient of variation; numbers followed by different letters between maturity stages showed significant differences based on the DMRT test at α = 0.05

Different dosages of amino acid fertilizer had no significant effect on the TSS content of Servo tomatoes. The TSS content is influenced by the maturity stage (Duma et al., 2015). The highest TSS content in the light red maturity stage occurs due to the activity of breaking down carbohydrates into simple sugars before the red stage which is influenced by temperature and solar radiation thereby accelerating carbohydrate biosynthesis (Adeoye et al., 2016). In addition, the TSS content in tomatoes is also affected by environmental stress in the form of water deficiency and salinity (Fukudome et al., 2022).

Table 6. Total titrated acid (TTA) tomato Servo on various treatments and maturity stages.

Treatment	TTA (%)
Amino acid fertilizer (0 L ha^{-1})	0.04a
Comparison fertilizer (2 L ha^{-1})	0.03b
Amino acid fertilizer (1 L ha^{-1})	0.03b
Amino acid fertilizer (2 L ha^{-1})	0.02b
Amino acid fertilizer (4 L ha^{-1})	0.03b
Note	*
CV (%)	13.08
Maturity stage	TTA (%)
Turning (4 DAH)	0.03q
Light red (11 DAH)	0.04pq
Red (24 DAH)	0.04p
Note	*
CV (%)	15.28

Note: DAH = days after harvest; * = significant at p-value < 0.05; CV = coefficient of variation; numbers followed by different letters show significantly different based on the DMRT test α = 0.05.

Different dosages of amino acid fertilizer had a significant effect on the TTA content of Servo tomatoes during the turning phase (4 DAH). Tests were also carried out at 11 DAH and 24 DAH but data were not presented. Testing for TTA content during the turning phase was carried out after the tomatoes were harvested without going through storage for a long time so that it was not much affected by storage climatic conditions but was influenced by pre-harvest factors in the form of fertilizer content. The TTA content is also affected by the maturity phase (Duma et al., 2015). Differences in TTA content in each maturity stage are influenced by the activity of the Krebs cycle in the use of organic acids (Tigist et al., 2013). The use of organic acids from the Krebs cycle as an energy source in

respiration tends to decrease as the maturity stage increases, resulting in significant differences in TTA content between maturity stages. The chemical quality of tomatoes is also influenced by the content of carotenoids, lycopene, flavonoids, and vitamin C.

Table 7. Servo tomato carotenoid content in various treatments and several stages of maturity.

Maturity stage	Carotenoid (mg 100g^{-1})					Mean
	AA fertilizer (0 L ha^{-1})	Comparison fertilizer (2 L ha^{-1})	AA fertilizer (1 L ha^{-1})	AA fertilizer (2 L ha^{-1})	AA fertilizer (4 L ha^{-1})	
Turning (4 DAH)	7.04	7.62	9.83	6.41	8.11	7.96c
Light red (11 DAH)	13.46	11.31	15.70	13.55	17.30	15.78a
Red (24 DAH)	11.11	10.73	10.57	11.78	11.71	11.45b
Note			ns			*
CV (%)						14.89

Note: AA = amino acid; DAH = days after harvest; * = significant at p-value < 0.05; ns = not significant; CV = coefficient of variation; numbers followed by different letters between maturity stages showed significant differences based on the DMRT test at α = 0.05.

Different dosages of amino acid fertilizer had no significant effect on the carotenoid content of Servo tomatoes. These results are following Armita et al. (2017), that differences in fertilizer content have no significant effect on carotenoid content. Differences in fertilizer content did not affect the activity of carotenoid biosynthesis. The carotenoid content is much influenced by the maturity stage, where the maturity stage before red contains the highest carotenoids (Bhandari & Lee, 2016). The carotenoid content which is affected by the maturity stage occurs due to differences in carotenoid biosynthetic activity in producing color pigments, with the highest activity occurring in the pre-red stage (Bhandari & Lee, 2016).

Table 8. Lycopene and vitamin C content of Servo tomatoes in various treatments.

Treatment	Lycopene (mg 100 g^{-1})	Vitamin C (mg 100 g^{-1})		
	Red (24 DAH)	Turning (4 DAH)	Light red (11 DAH)	Red (24 DAH)
Amino acid fertilizer (0 L ha^{-1})	7.69	36.92	35.90	22.00
Comparison fertilizer (2 L ha^{-1})	8.15	33.74	20.00	21.90
Amino acid fertilizer (1 L ha^{-1})	8.15	36.82	22.67	21.38
Amino acid fertilizer (2 L ha^{-1})	7.88	21.54	29.13	22.72
Amino acid fertilizer (4 L ha^{-1})	9.39	36.41	22.87	22.82
Note	ns	ns	ns	ns

Note: DAH = days after harvest; CV = coefficient of variation; ns = not significant.

Different dosages of amino acid fertilizer had no significant effect on the content of lycopene and vitamin C in Servo tomatoes. However, the higher the nitrogen content in fertilizers, the lower the vitamin C content through an imbalance between free radicals and antioxidants or oxidative stress (Ochoa-Velasco et al., 2016). Also, the addition of nitrogen and potassium can increase the lycopene content through enzyme activation and pigment synthesis (Frías-Moreno et al., 2020). Meanwhile, the maturity stage has no significant effect on the vitamin C content because the biosynthesis of vitamin C is more influenced by environmental factors, the content of ethylene gas, and reducing sugars in tomatoes (Valšíková-Frey et al., 2018). One of the environmental factors that affect the vitamin C content in tomatoes is the intensity of sunlight. High sunlight intensity can increase enzyme activity that plays a role in the synthesis of vitamin C by increasing the rate of photosynthesis to form carbohydrates which are precursor materials for the formation of vitamin C (Ntagkas et al., 2019).

Table 9. Flavonoid content of Servo tomato in various treatments and maturity stages.

Maturity stage	Flavonoid (mg kg^{-1})					Mean
	AA fertilizer (0 L ha^{-1})	Comparison fertilizer (2 L ha^{-1})	AA fertilizer (1 L ha^{-1})	AA fertilizer (2 L ha^{-1})	AA fertilizer (4 L ha^{-1})	
Turning (4 DAH)	5.72	3.78	3.29	3.43	6.56	4.56b
Light red (11 DAH)	8.22	3.71	5.10	7.81	7.39	6.44ab
Red (24 DAH)	7.81	9.68	9.61	6.14	8.22	8.29a
Note			ns			*
CV (%)						16.91

Note: AA = amino acid; DAH = days after harvest; * = significant at p-value < 0.05; ns = not significant; CV = coefficient of variation; numbers followed by different letters show significantly different based on the DMRT test at α = 0.05

Different dosages of amino acid fertilizer had no significant effect on the flavonoid content. Meanwhile, different content of fertilizers does not affect the content of flavonoids because the biosynthetic activity of flavonoids is more influenced by genes and the maturity stage (Deng et al., 2018). Differences in the maturity stage can affect the flavonoid content through a biosynthetic which increases with increasing stage (Nikolaos et al., 2018).

Table 10. Commercial storability of tomato Servo.

Treatment	Commercial storability (days)
Amino acid fertilizer (0 L ha^{-1})	44.00±0.87
Comparison fertilizer (2 L ha^{-1})	40.17±3.82
Amino acid fertilizer (1 L ha^{-1})	40.17±4.19
Amino acid fertilizer (2 L ha^{-1})	37.33±5.35
Amino acid fertilizer (4 L ha^{-1})	44.83±0.29
Note	ns

Note: DAH = days after harvest; ns = not significant.

Different dosages of amino acid fertilizer had no significant effect on the shelf life of Servo tomatoes. Tomatoes that have the longest shelf life are tomatoes treated with 4 L ha^{-1} amino acid fertilizer. This happens because the dominant amino acid content causes an increase in fruit firmness (El-Badawy, 2019). Plants with a high supply of amino acids cause the formation of extra pectin which is harder between the cell walls. This resulted in the resulting Servo tomato exocarp being thicker thereby minimizing mechanical damage at the end of the observation. Meanwhile, the shelf life was also affected by the condition of the tomatoes at the start of storage and the pathogenic infections that occurred during storage.

CONCLUSIONS

Amino acid fertilizer can improve the quality of Servo tomatoes as seen from the parameters of fruit color (a*) and total titrated acid (TTA). In terms of other parameters, the amino acid fertilizer does not affect the quality of Servo tomatoes. The highest value on fruit color (a*) and TTA resulted from 2 L ha^{-1} of amino acid fertilizer. Meanwhile, the maturity stage significantly affects the quality improvement of fruit firmness, weight loss, VQR, CO_2 concentration, total titrated acid content, total soluble solids, carotenoids, and flavonoids. Overall, the addition of 4 L ha^{-1} amino acid fertilizer was insignificantly able to increase the commercial shelf life of tomatoes for 4 days compared to the control.

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