

Original Research Article

## Effect of Temperature and Oxygen Concentration on the Quality of Shallots (*Allium cepa* var *ascalonicum* L. Back) in Modified Atmosphere Storage (MAS)

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**Abstract:** Shallots have a relatively short shelf life and are easily damaged. It is necessary to find an effective, yet affordable technology for managing the quality of shallot seeds. Modified Atmosphere Storage (MAP) is a promising storage method to maintain the quality of agricultural products, including shallots. The research aims to determine the effect of storage time, storage temperature, and O<sub>2</sub> concentration on the quality of shallot seed. A three-way repeated measures design was applied to run this research; the first factor was the storage time (9 weeks), the second factor was storage temperature (5°C, 15°C, and 28°C), and the third factor was O<sub>2</sub> concentration (5%, 10%, and 21%). Colour components (L, a\*, b\*), hue angle (h\*), chroma (C\*), colour difference ( $\Delta E$ ), total soluble solid content (TSSC), and bulb hardness (F) were measured every week to evaluate the quality of shallots during storage. It was found that the values of b\*, h\*,  $\Delta E$ , and TSSC of shallots increased, while the L\*, a\*, C\*, and F decreased during storage in the modified atmosphere condition. In general, the storage temperature at 5°C with 5% O<sub>2</sub> concentration showed the best parameter values. This storage condition had the lowest b\* value, the lowest h\* value, the lowest TSSC value, and the highest F value. While other parameters, such as L, a\*, C\*, and  $\Delta E$ , although not at the lowest or highest, were also in fairly low ranges. Therefore, this storage treatment was concluded as the best storage treatment for shallots. It could also be concluded that the effect of storage temperature on shallot parameters was much stronger than that of O<sub>2</sub> concentration.

**Keywords:** Shallots; MAS; oxygen; temperature; quality

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## 1. Introduction

The demand for shallots in Indonesia continues to increase along with population growth and increased consumption. National shallot production also continues to increase, but still unable to fully meet the demand. Shallots have a relatively short shelf life; this characteristic can hinder the supply of raw materials, especially fresh ones. This is because, in general, horticultural products that are still alive are still experiencing chemical and biochemical changes due to metabolic activity (Basha *et al.*, 2023; Sukorini, 2024). Onion crops are still a living product, so they are easily damaged. Damage that occurs, such as the softening of bulbs, developing wrinkles, becoming porous, rotting, sprouting, root growth and mould growth. Damage to the storage process will cause high weight loss and decreased quality of shallot bulbs (David, 2022).

Postharvest activities to protect onion quality during storage can include low temperature, application of mitotic inhibitors and atmosphere with ethylene (Sharma *et al.*, 2014). One treatment is leaf cutting followed by storage, which is an alternative treatment to protect shallots from decay and facilitate further handling (Amiarsi *et al.*, 2019). Smoking technology is one method for preservation. This process occurs due to the presence of phenol compounds, acids, and other components that are antimicrobial, antioxidant, and disinfectant (Ricardo-Rodrigues *et al.*, 2024). Soaking shallots for 2 hours in liquid smoke helps maintain their physical and chemical properties without changing their sensory characteristics (Aini & Karseno, 2021). Meanwhile, according to Nurmali (2019) storage at low temperatures can inhibit microbial growth, enzymatic, and chemical reactions that slow down the process of decay and damage and make the material more durable. However, all these technologies are still not optimal for maintaining the quality of shallots during storage.

Modified atmosphere packaging (MAP) has been proven to be an efficient technique to extend the shelf life of fruits and vegetables, and also, proper packaging will maintain the colour, texture, and nutritional quality attributes of the product (Mangaraj *et al.*, 2009). However, this technology is less applicable and inefficient for large volumes of vegetable or fruit harvests. Controlled Atmosphere Storage (CAS) is an effective technology in maintaining the quality and extending the shelf life of fruits or vegetables by controlling or conditioning the concentration of the composition of the gas content in the storage room so that the fruit or vegetable will be inhibited in the ripening process. However, the economic value of obtaining and using this technology is still a major obstacle to its application in society, as it is still very expensive (Chope *et al.*, 2007; Suwandi *et al.*, 2024).

There is a need for technologies that are close to effective in managing the quality of shallots, yet cost-effective for the community. One of them may be the utilisation of modified atmosphere storage (MAS). MAS is the preservation method that maintains the natural quality of products and extends the storage period. The storage period of food products can be extended by modifying the atmosphere around the food, which reduces the respiration rate of food products and the activity of microorganisms in the food (Jayas & Jeyamkondan,

2002). Therefore, it is necessary to test the effectiveness and applicability of MAS technology.

Various parameters can be used to describe the quality of shallots, including colour components (L, a\*, and b\*), chroma, hue angle, colour difference, bulb hardness (F), and total soluble solid content (TSSC). Changes in the values of these parameters can be used to evaluate the performance and effectiveness of the storage method used.

Storage temperature significantly affects the colour of agricultural products by regulating ripening processes such as respiration and enzymatic activity. Low temperatures generally slow these processes, preserving colour and slowing degradation, while high temperatures accelerate them, causing more rapid colour changes and potentially increasing microbial activity and mould growth. It was reported that the peel colour of shallots changed from light red-purple ( $^{\circ}\text{hue} = -0.18$ ) on week 0 to red-yellow ( $^{\circ}\text{hue} = 0.50 - 0.62$ ) on week 12, where for the shallots stored at low temperature, the peel colour change process was slower than room temperature storage (Fauziah *et al.*, 2020).

Sukorini (2024) found that storing shallots without fogging at a lower temperature (18°C) will maintain better F value than storing at higher temperatures (22 and 26°C). Meanwhile, the TSSC value was reported to increase with increasing storage temperature in shallots that did not undergo fogging treatment.

This study aimed to evaluate the effect of MAP in the form of variations in storage temperature and O<sub>2</sub> concentration in the storage room on changes in the quality of shallot seeds. Until now, no research has been conducted that combines the effects of both treatment factors, namely temperature and O<sub>2</sub> concentration in the storage room, on changes in the quality of shallots.

## 2. Materials and Methods

### 2.1. Materials and Tools

The shallots used in this study were harvested by farmers, dried, and sorted according to the requirements for shallot seeds. The shallot seed variety used was “Tajuk”, which was obtained from shallot farmers in the Parangtritis area, Bantul, Yogyakarta, Indonesia. The diameter of the shallot bulb ranged from 0.49-0.54 cm, with a length of 1.8-3.9 cm, the weight per bulb was 6.5-13.68 g, reddish in colour with values of L = 50.85, a\* = 22.15, and b\* = 6.97 and a F level of 554.38 kgf.



**Figure 1.** The shallot materials used for the study

## 2.2. Methods

The research used a three-way repeated measures design, where the first factor was the storage time (9 weeks), the second factor was O<sub>2</sub> concentration consisted 3 levels (5%, 10%, and 21%), while the third factor was the storage room temperature, which also consisted of 3 levels (5°C, 15°C, and 28°C) (Soltani *et al.*, 2015). Storage temperatures of 5°C and 15°C were carried out in cold storage (Polytron SCN 140X, Re134a/80g, Indonesia), while 28°C was carried out in an open room (room temperature) during the research. The temperature of the storage room, including the environmental temperature, was monitored continuously, where the average environmental temperature during the research was 28°C. Humidity in the storage room was monitored using a hygrometer (Dekko 642N, range 10-99%, resolution 1%, South Korea) and was found to be in a uniform condition for all storage rooms in the range of 70-80% (Jongen, 2002). Shallot samples were stored in closed system jars with oxygen content according to the treatment and placed according to the temperature treatment.

Shallot samples were stored using thick, airtight glass jars. To create a low O<sub>2</sub> concentration in the glass jar, the O<sub>2</sub> concentration was adjusted by flushing it with N<sub>2</sub> gas until the O<sub>2</sub> concentration in the jar reached the desired level in the study. O<sub>2</sub> concentration measurements were performed using an O<sub>2</sub>-CO<sub>2</sub> gas analyser (Quantek 902D). For a 21% O<sub>2</sub> concentration, ambient air conditions were used. The glass jar was opened once a week for sample collection and then readjusted to the desired O<sub>2</sub> level to continue the study. Storage was carried out for 56 days, and each treatment combination was repeated 3 times.

## 2.3. Measured Parameters

There were 3 parameters related to the quality of shallot bulbs characterised by colour, hardness, and durability of shallot bulb freshness during storage (Brix value approach) (Woldetsadik & Workneh, 2010).

### 2.3.1. Colour

In this study, the colour of shallots sample was determined by using a colourimeter (Sucolor model SC – 10) based on the CIELab measurement standard. L indicated the lightness value and ranged from 0 to 100 (black to white), a\* and b\* indicated the colour range from green to red (redness) and blue to yellow (yellowness) from negative to positive on the horizontal and vertical axes (Gundewadi *et al.*, 2018).

Based on the results of this colour measurement, the chroma (C\*) was calculated by using Equation 1. C\* values represented colour saturation with red-purple at 0, yellow at 90, grey-green at 180 and blue at 270°, counterclockwise (McGuire, 2019; Souza *et al.*, 2018; Malakar *et al.*, 2020).

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (1)$$

Hue angle (h\*) represented the tone according to the angle on the 360 colour wheel; this value was calculated using Equation 2 (Manera *et al.*, 2012; Petropoulos *et al.*, 2016).

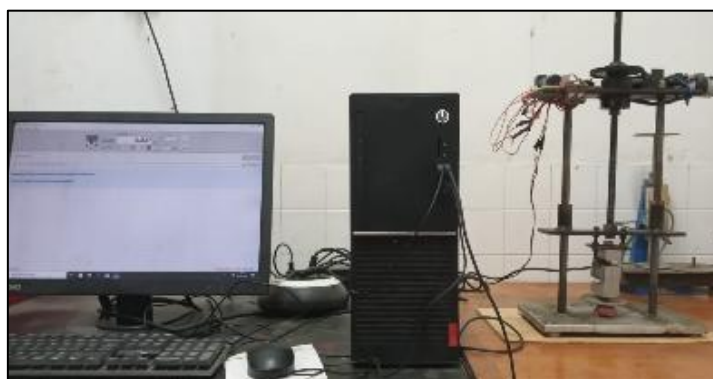
$$h^* = \arctan\left(\frac{b^*}{a^*}\right) \times 57,3 \quad (2)$$

Meanwhile, the colour difference ( $\Delta E^*$ ) was determined using Equation 3 (Kortei *et al.*, 2015; Devgan *et al.*, 2019).

$$\Delta E^* = [(L_0 - L^*)^2 + (a_0 - a^*)^2 + (b_0 - b^*)^2]^{1/2} \quad (3)$$

### 2.3.2. Hardness (F)

The F value of the shallot bulb was determined using a compressive test equipment consisting of a load cell (LGT type LAS-100 kg), an interface (Loadstar LV-1000) attached to the computer. The whole shallot bulb was used for hardness measurement. In the measurement, the shallot bulb was placed in its natural resting position (horizontal) on the base of the compression tester. Then, pressure was applied until the bulbs ruptured. The maximum pressure value was then recorded as research data for further analysis.



**Figure 2.** The shallot pressure tested

### 2.3.3. Total soluble solids content (TSSC)

TSSC of the shallot sample was measured using a digital refractometer (Atago, type Pal- $\alpha$  3840 with a measurement range of 0–85%/0.1%). The measurement of TSSC was done by pressing the shallot sample until the liquid was released. The collected liquid was then dripped onto the refractometer sensor, and the TSSC value would directly appear on the refractometer.

### 2.4. Data Analysis

All measurement data were tested using analysis of variance with a three-way repeated measures design. This statistical analysis would demonstrate the influence of the three factors tested: storage time, storage temperature, and oxygen concentration. In addition, the interaction effects of these three treatment factors would also be obtained. The Duncan Multiple Range Test (DMRT) was used to compare treatment means. All tests used a significant level of 0.05 (5%).

## 3. Results and Discussions

### 3.1. Colour



**Figure 3.** The shallot prior to storage and after 56 days

Figure 3 shows the colour of the shallot samples used in the study, both initially and after 56 days of storage under various treatments. Visually, the colour of the shallot samples was observed to change, and this was further confirmed by measurements and analysis of the L, a\*, and b\* values of the samples.

#### 3.1.1. Lightness (L)

Shallot shelf life is influenced by several factors, one of which is the skin colour (Nega *et al.*, 2015; Shivakumar & Chandrashekar, 2014). Table 1 presents the values of L of shallot samples in each treatment combination tested during 56 days of storage. It could be observed that L values of the shallots consistently decreased with increasing storage time. This decrease in the L value is thought to be related to a decrease in the anthocyanin pigment, which gives the shallot its red colour. As the anthocyanin degraded, the colour of the shallots

would become darker, which meant that the L value would decrease. Al-Baari *et al.* (2023) also reported that the L value of shallot paste decreased with longer storage time.

**Table 1.** Changes in the L value of shallot samples in each treatment combination tested during 56 days of storage

Treatment	Storage period (days)									$\Delta L^*$
	0	7	14	21	28	35	42	49	56	
T 28°C+O <sub>2</sub> 21%	49.03	48.49	49.53	49.70	49.50	49.54	49.49	48.33	48.14	-0.89
T 28°C+O <sub>2</sub> 10%	53.01	52.19	52.20	52.28	52.33	52.20	52.00	51.81	51.56	-1.45
T 28°C+O <sub>2</sub> 5%	52.75	51.59	50.98	50.58	51.26	51.40	51.89	51.37	50.48	-2.26
T 15°C+O <sub>2</sub> 21%	51.21	49.44	48.51	48.65	48.94	48.47	48.82	48.10	47.66	-3.54
T 15°C+O <sub>2</sub> 10%	51.15	47.95	47.94	47.27	47.05	47.64	47.88	47.66	48.27	-2.88
T 15°C+O <sub>2</sub> 5%	51.80	48.02	48.08	47.52	48.36	48.22	48.29	47.46	48.01	-3.79
T 5°C+O <sub>2</sub> 21%	52.29	48.05	47.01	46.45	46.23	45.89	45.39	45.22	44.17	-8.12
T 5°C+O <sub>2</sub> 10%	52.37	49.47	48.09	47.38	47.56	46.94	46.42	47.09	46.66	-5.71
T 5°C+O <sub>2</sub> 5%	52.27	49.17	47.16	47.81	48.13	47.31	47.54	47.69	47.30	-4.98

\*)  $\Delta L$  values: (+) increase, (-) decrease compared to the initial value (0 day)

L values at the end of storage ranged from 44.17 to 51.56; the higher the L value, the lighter or brighter the shallots would appear. The difference between the L value at the beginning and end of storage ( $\Delta L$ ) could be used to determine the level of change in the L value of the shallot sample being tested. Based on this  $\Delta L$  value, it was found that storage at a temperature of 5°C provided the greatest change in  $\Delta L$  as compared to storage temperatures of 15 and 28°C for all O<sub>2</sub> concentrations tested. This shows that storing shallots at cold temperatures might accelerate colour dullness.

### 3.1.2. Redness ( $a^*$ )

The colour of fruits and vegetables changes at the beginning of the ripening process due to the accumulation of various pigments namely  $\beta$ -carotene (mango, carrot), anthocyanins - pink to blue (apple, strawberry, onion, rose), lycopene (tomato, watermelon, papaya, pink guava, grape), xanthophyll (papaya), and violaxantin (orange) (Gundewadi *et al.*, 2018). It was observed that the  $a^*$  value of shallots decreased with increasing storage time (Table 2). This decrease was thought to be caused by the degradation of colour pigments, especially anthocyanins, due to the presence of O<sub>2</sub>, heat, and light during storage.

The  $a^*$  values at the end of storage ranged from 11.80 to 19.79, where the difference of  $a^*$  between the initial and final storage conditions ( $\Delta a^*$ ) showed that storage at 15°C produced the lowest  $\Delta a^*$  value for all O<sub>2</sub> concentrations studied. This indicates that storing shallots at 15°C inhibited red colour degradation better than storage temperatures of 5 and 28°C.

**Table 2.** Changes in the a\* value of shallot samples in each treatment combination tested during 56 days of storage

Treatment	Storage period (days)									$\Delta a^*$
	0	7	14	21	28	35	42	49	56	
T 28°C+O <sub>2</sub> 21%	21.32	19.46	21.01	19.28	18.29	19.03	17.13	15.57	11.80	-9.52
T 28°C+O <sub>2</sub> 10%	18.44	18.08	18.03	17.01	17.09	17.28	16.52	14.42	12.46	-5.98
T 28°C+O <sub>2</sub> 5%	16.76	18.30	18.82	17.82	18.47	17.47	17.56	17.06	13.14	-3.63
T 15°C+O <sub>2</sub> 21%	20.20	20.74	19.47	19.33	19.70	19.24	19.52	19.47	19.79	-0.41
T 15°C+O <sub>2</sub> 10%	19.48	19.93	19.50	20.09	19.46	19.26	19.26	18.43	18.29	-1.19
T 15°C+O <sub>2</sub> 5%	19.32	19.72	19.84	18.92	19.43	20.02	19.17	20.01	19.36	0.04
T 5°C+O <sub>2</sub> 21%	20.23	20.57	19.57	20.86	20.09	18.59	18.66	17.92	16.97	-3.26
T 5°C+O <sub>2</sub> 10%	19.30	20.27	19.58	20.51	19.99	19.49	18.45	18.60	17.89	-1.40
T 5°C+O <sub>2</sub> 5%	19.42	19.04	19.74	18.84	18.33	18.65	19.02	17.62	16.41	-3.00

\*)  $\Delta a^*$  values: (+) increase, (-) decrease compared to the initial value (0 day)

### 3.1.3. Yellowness ( $b^*$ )

Table 3 shows the changes in the  $b^*$  colour component of the shallot samples during storage. It could be observed that the  $b^*$  value consistently increased during storage in all treatments studied. It was suggested that the accumulation of less colourful carbinol compounds caused the  $b^*$  value to increase. The carbinol compounds would degrade into colourless or yellowish chalcone compounds if the storage temperature continues to increase and the storage duration is extended. Chalcone compounds were visually colourless and might cause an increase in positive  $b^*$  values (Nofrida *et al.*, 2013).

**Table 3.** Changes in the  $b^*$  value of shallot samples in each treatment combination tested during 56 days of storage

Treatment	Storage period (days)									$\Delta b^*$
	0	7	14	21	28	35	42	49	56	
T 28°C+O <sub>2</sub> 21%	3.82	3.86	4.89	7.18	7.87	7.54	8.79	9.58	11.28	7.46
T 28°C+O <sub>2</sub> 10%	3.30	3.31	3.50	5.53	6.06	6.37	7.85	8.49	9.63	6.33
T 28°C+O <sub>2</sub> 5%	6.02	6.49	8.28	7.91	8.67	10.70	9.49	9.48	10.64	4.63
T 15°C+O <sub>2</sub> 21%	3.66	4.20	3.88	5.87	5.77	6.17	6.91	7.06	8.37	4.71
T 15°C+O <sub>2</sub> 10%	3.26	3.32	3.89	4.81	5.87	6.31	6.14	6.61	7.92	4.66
T 15°C+O <sub>2</sub> 5%	5.15	5.02	4.88	6.25	6.32	7.13	6.84	6.81	9.30	4.15
T 5°C+O <sub>2</sub> 21%	3.70	3.23	3.36	3.36	4.02	5.11	6.34	6.93	7.33	3.63
T 5°C+O <sub>2</sub> 10%	4.16	4.77	5.51	5.50	5.40	6.67	7.16	6.94	7.31	3.15
T 5°C+O <sub>2</sub> 5%	3.71	2.97	3.94	4.34	4.36	5.18	6.21	6.46	6.84	3.13

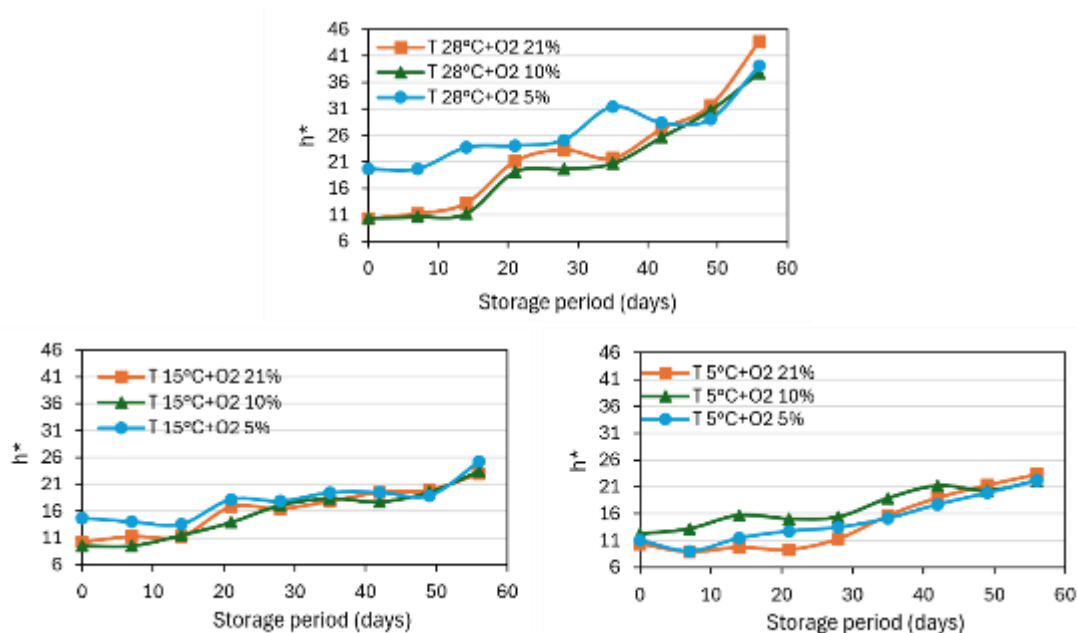
\*)  $\Delta b^*$  values: (+) increase, (-) decrease compared to the initial value (0 day)

The colour value of shallots tends to increase to yellowish during storage, due to chemical reactions that affect the colour pigments. Anthocyanin pigments that give shallots

their red colour could turn yellow or disappear due to various factors, such as exposure to oxygen, heat, and light. The difference of  $b^*$  values between the initial and end of storage ( $\Delta b^*$ ) showed that the values of  $\Delta b^*$  differed according to storage temperature and  $O_2$  concentration. It was indicated that temperature and oxygen concentration affected the change in the  $b^*$  of shallot samples. The value of  $\Delta b^*$  for storage temperature of  $5^\circ C$  consistently indicated a lower value than storage temperature of 15 and  $28^\circ C$  for all of the  $O_2$  concentration studied. The smallest  $\Delta b^*$  value resulted from storage at  $5^\circ C$  and 5%  $O_2$  concentration. This indicated that this storage condition was the best for maintaining  $\Delta b^*$  colour changes.

#### 3.1.4. Hue angle ( $h^*$ )

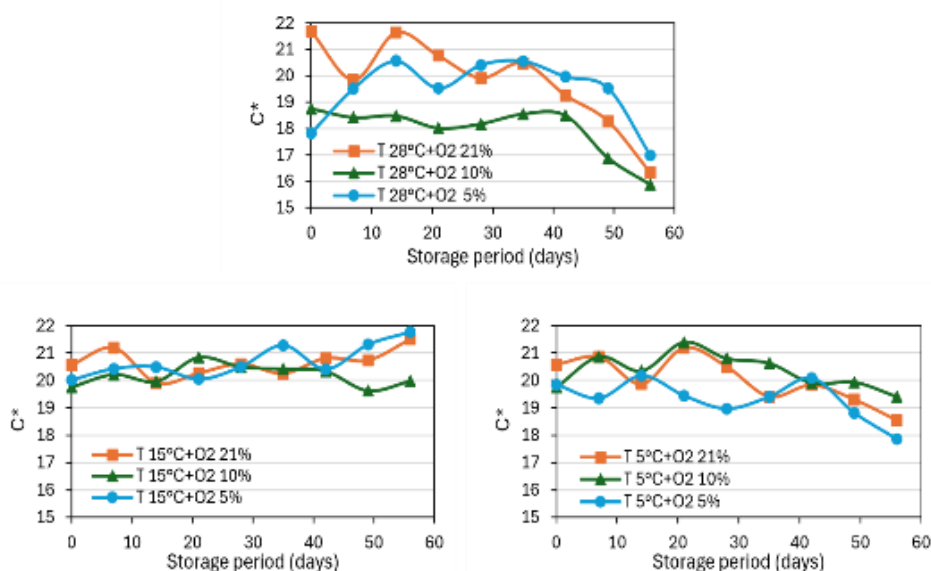
Figure 4 presents the  $h^*$  value for all studied treatments during storage. It was found that  $h^*$  consistently increased during storage for all treatments. Increased  $h^*$  values of shallots during storage meant a change in colour from red ( $h^* \leq 15$ ) to more yellow ( $h^* \leq 75$ ) or orange ( $h^* \leq 45$ ). This could be an indication of natural colour change or the effect of environmental factors during storage, such as temperature, humidity, and light exposure. It could also be observed that all treatments experienced a red to orange change during storage. The increase in  $h^*$  value ranged from 9.94–33.41, where a low temperature of  $5^\circ C$  and a low  $O_2$  of 5% had the smallest  $\Delta h^*$  value. This indicated that this storage condition was the best in maintaining  $\Delta h^*$  of the shallot. On the other hand, this also meant that increasing temperature and oxygen concentration would increase the  $\Delta h^*$  value, and this condition was in accordance with the phenomenon that the respiration rate of fruits and vegetables was influenced by storage conditions, such as temperature, air composition, humidity and lighting and finally resulted in a larger change of  $\Delta h^*$  (Suwandi, 2024).



**Figure 4.** Graph of hue angle values during shallot bulb storage

### 3.1.5. Chroma ( $C^*$ )

Chroma indicates how strong or saturated the colour of an object is. This means that the smaller the  $C^*$ , the lower the brightness, or it indicates a colour that is not strong. Figure 5 shows the  $C^*$  values of all the treatments studied. During storage, the shallots underwent various changes, such as respiration, water loss, and physical damage. These processes could affect the colour of the shallot and cause loss of chroma. It could be observed that  $C^*$  value consistently decreased during storage for storage temperature of  $5^\circ\text{C}$  (0.34–2.03) and  $28^\circ\text{C}$  (0.84–5.36) in all  $\text{O}_2$  concentrations. The decrease in  $C^*$  value during storage indicated that the colour intensity of shallots fades. However, at a storage temperature of  $15^\circ\text{C}$ , the values of  $C^*$  were found to increase for  $\text{O}_2$  at all concentrations of 5, 10, and 21% (0.22–1.75). This phenomenon showed that storage at a temperature of  $15^\circ\text{C}$  was the most capable in maintaining the  $C^*$  value of the studied shallot.

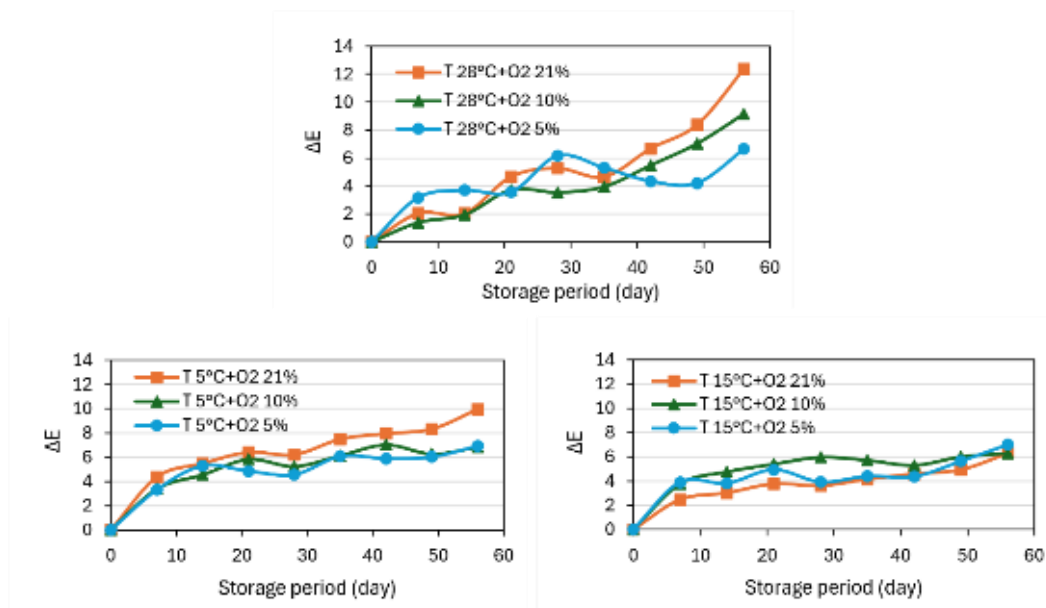


**Figure 5.** Graph of Chroma values during shallot bulb storage

### 3.1.6. Colour difference ( $\Delta E$ )

$\Delta E$  was a measure of the colour difference between two colours point of measurement. The greater the  $\Delta E$  value, the greater the colour difference or colour change. Figure 6 presents the values of  $\Delta E$  during storage for all of the treatments studied. It could be observed that  $\Delta E$  consistently increased during storage, regardless of the storage temperature of  $28^\circ\text{C}$  (6.65–12.35),  $15^\circ\text{C}$  (6.28–7.01), or  $5^\circ\text{C}$  (6.83–9.96).

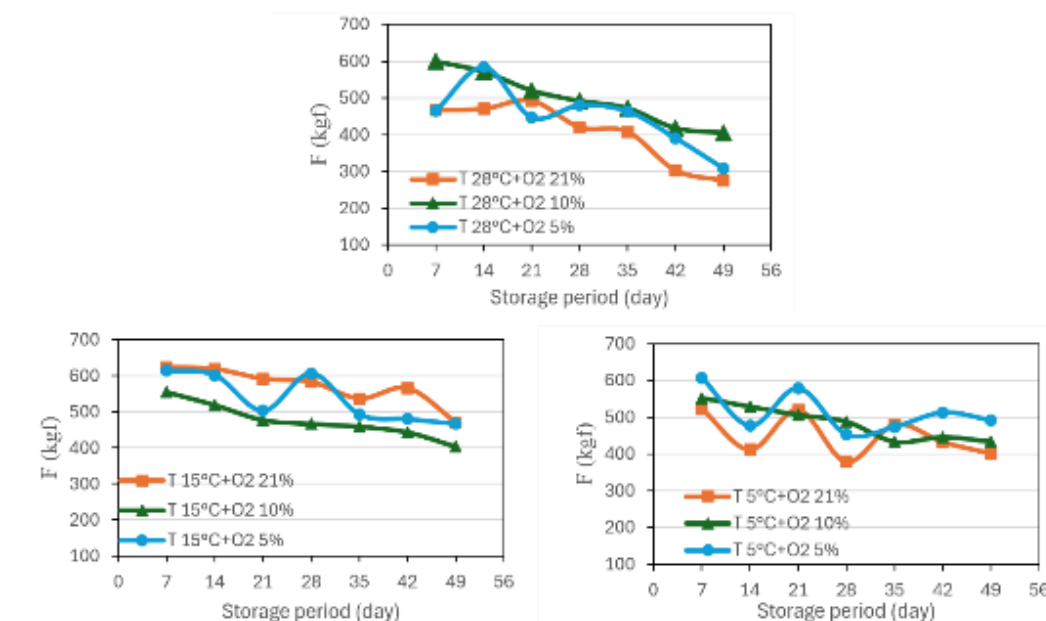
The increase of  $\Delta E$  value during storage indicated that the colour of the shallots became more faded, dull, or changed to a less desirable colour. The ripening process of fruits and vegetables might be suppressed by decreasing temperature, oxygen levels, and lighting in MAS (Pérez-López *et al.*, 2020). Ripening of fruits and vegetables needs different times, this is because fruits or vegetables have different  $\text{CO}_2$  sensitivities (Cefola *et al.*, 2023).



**Figure 6.** Graph of Delta E values during shallot bulb storage

### 3.2. Hardness (F)

Figure 7 presents the results of shallot F values for all treatments studied. Hardness of shallot samples consistently decreased during storage for all the treatments studied. The low F level indicated a softened shallot texture. This might occur due to changes in cell wall composition, which was one of the softening mechanisms that commonly occurred in fruit ripening. The level of F depended on the thickness of the outer skin, total solids, and starch content of a material (Pangidoan *et al.*, 2014).

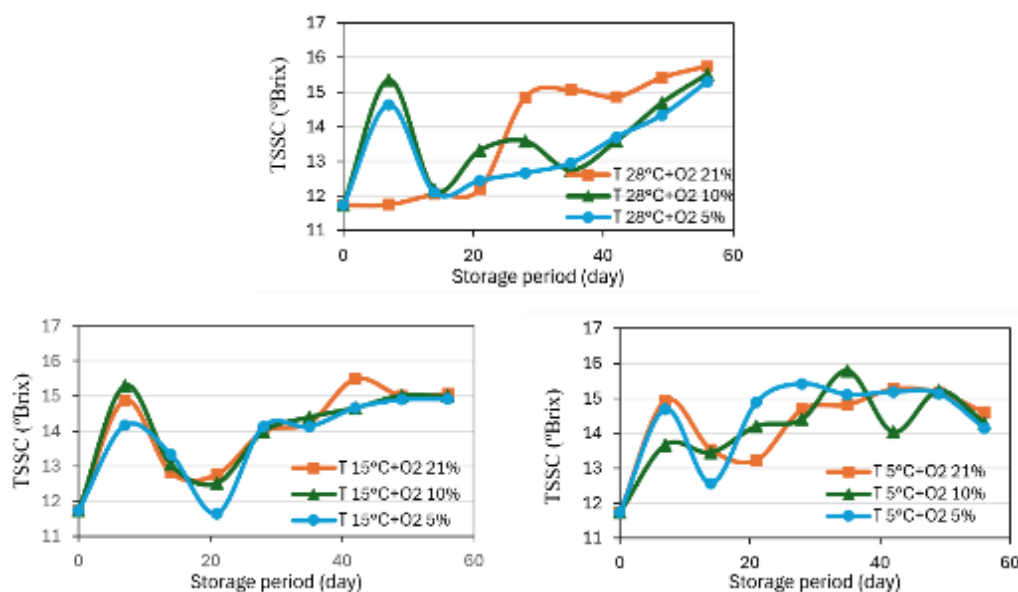


**Figure 7.** Graph of Hardness during shallot bulb storage

It could be observed that storage temperature and O<sub>2</sub> concentration influenced the decrease in the F values of shallots during storage. The treatment of 5°C and 5% O<sub>2</sub> was found to have the smallest decrease in F value. These conditions indicated that shallot storage at low temperature combined with low oxygen concentration (5°C + 5% O<sub>2</sub>) was a better method to maintain shallot F value during storage. Low temperature and O<sub>2</sub> concentration could slow down metabolic processes and respiration, and reduce water loss, so that shallots could be maintained in fresh and firm conditions longer.

### 3.3. Total Soluble Solids Content (TSSC)

TSSC were defined as all existing solids and water-soluble solids in the bulbs, including reduced sugars, sucrose, organic acids and water-soluble vitamins. Figure 8 shows the TSSC of all studied treatments. It was observed that TSSC increased during storage for all of the treatments. According to Djali & Rachmat (2013), changes in TSSC were related to the pattern of changes in water content, which caused a decrease in water content that ultimately increases TSSC content. It was also stated that the increase in TSSC was caused by metabolic processes involving the conversion of starch and acids into sugars (Mannozi *et al.*, 2017; Adi *et al.*, 2019).



**Figure 8.** Graph of total soluble solids (TSS) during shallot bulb storage

Storage temperature and O<sub>2</sub> concentration increased the TSSC of shallots during storage. The treatment of 5°C + 5% O<sub>2</sub> had the smallest increase in TSSC value, namely for 5°C (2.42–2.87°brix), 15°C (3.18–3.33°brix) and 27°C (3.57–4.02°brix). These conditions indicated that shallot storage at low temperature and O<sub>2</sub> concentration (5°C and 5% O<sub>2</sub>) was a better method to maintain shallot hardness during storage. Low temperature and O<sub>2</sub> concentration could slow down metabolic processes and respiration, and reduce water loss, so that shallots stayed fresh and firm longer (Nawab *et al.*, 2017; Imahori *et al.*, 2021). The

high storage temperature caused respiration to take place faster, and transpiration occurred from the product to the environment, so that samples stored in the higher temperature tended to deteriorate or change their quality faster (Edusei *et al.*, 2021).

### 3.4. Statistical Analysis Results

Table 4 shows a summary of the results of the analysis of variance using repeated measures ANOVA for all parameters measured in the study. The summary of the results of this analysis showed that storage time, the interaction between storage time and storage temperature, and storage temperature had a significant influence on all parameters studied ( $p < 0.05$ ). This indicated that storage time and temperature were the factors that most influenced changes in the values of the parameters studied. In general, the F value and TSSC were significantly influenced by all treatment factors, including all interactions ( $p < 0.05$ ). This indicates that these two parameters are highly sensitive, or their values are most easily affected by storage time, temperature, and O<sub>2</sub> concentration compared to other parameters.

**Table 4.** Relationship between time, temperature, and storage room oxygen on the quality of shallot bulbs

Parameters	Factors						
	t	Interaction t x T	interaction t x O	interaction t x T x O	T	O	interaction T x O
L	*	*	ns	ns	*	ns	ns
a*	*	*	ns	ns	*	ns	ns
b*	*	*	ns	ns	*	ns	ns
H*	*	*	ns	ns	*	ns	ns
C*	*	*	ns	ns	*	ns	ns
ΔE	*	*	*	ns	*	ns	ns
F	*	*	ns	*	*	*	*
TSS	*	*	*	*	*	*	*

t = storage time, O = O<sub>2</sub> concentration, T= storage temperature, \* = indicates a significant effect, ns= not significant

Tables 5 and 6, respectively, show the results of the DMRT analysis for the effect of storage room temperature and O<sub>2</sub> concentration on all parameters studied. It could be observed that significant differences occurred in all parameters studied, although not all of them. This indicated that the treatments applied had unequal impacts on these parameter values. In general, the storage temperature at 5°C with 5% O<sub>2</sub> concentration showed the best values, although not for all parameters studied (Table 5). This treatment had the lowest b\* value, the lowest h\* value, the lowest TSSC value, and the highest F value. While other parameters, such as L, a\*, C\*, and ΔE, although not the lowest or highest, were also in a low range. Therefore, this storage treatment was concluded as the best storage treatment for shallots.

**Table 5.** DMRT results of colour, TSSC, and F of shallot bulbs during storage

Treatment	L	a*	b*	h*	C*	$\Delta E^*$	TSSC	F
T 28°C+O <sub>2</sub> 21%	48.14 <sup>bc</sup>	11.80 <sup>a</sup>	11.28 <sup>c</sup>	43.69 <sup>b</sup>	16.33 <sup>ab</sup>	12.35 <sup>c</sup>	15.75 <sup>f</sup>	275.28 <sup>a</sup>
T 28°C+O <sub>2</sub> 10%	51.56 <sup>d</sup>	12.46 <sup>a</sup>	9.63 <sup>abc</sup>	37.80 <sup>b</sup>	15.87 <sup>a</sup>	9.14 <sup>abc</sup>	15.52 <sup>e</sup>	405.15 <sup>c</sup>
T 28°C+O <sub>2</sub> 5%	50.48 <sup>cd</sup>	13.14 <sup>a</sup>	10.64 <sup>bc</sup>	39.16 <sup>b</sup>	16.98 <sup>abc</sup>	6.65 <sup>ab</sup>	15.30 <sup>d</sup>	308.36 <sup>b</sup>
T 15°C+O <sub>2</sub> 21%	47.66 <sup>bc</sup>	19.79 <sup>c</sup>	8.37 <sup>abc</sup>	22.92 <sup>a</sup>	21.50 <sup>fg</sup>	6.28 <sup>a</sup>	15.07 <sup>c</sup>	469.65 <sup>e</sup>
T 15°C+O <sub>2</sub> 10%	48.27 <sup>bc</sup>	18.29 <sup>bc</sup>	7.92 <sup>abc</sup>	23.45 <sup>a</sup>	19.98 <sup>ef</sup>	6.30 <sup>a</sup>	15.00 <sup>c</sup>	402.78 <sup>c</sup>
T 15°C+O <sub>2</sub> 5%	48.01 <sup>bc</sup>	19.36 <sup>c</sup>	9.30 <sup>abc</sup>	25.22 <sup>a</sup>	21.76 <sup>g</sup>	7.01 <sup>ab</sup>	14.92 <sup>c</sup>	466.71 <sup>e</sup>
T 5°C+O <sub>2</sub> 21%	43.69 <sup>a</sup>	16.97 <sup>bc</sup>	7.33 <sup>ab</sup>	23.38 <sup>a</sup>	18.54 <sup>cde</sup>	9.96 <sup>bc</sup>	14.60 <sup>b</sup>	401.45 <sup>c</sup>
T 5°C+O <sub>2</sub> 10%	46.66 <sup>ab</sup>	17.89 <sup>bc</sup>	7.31 <sup>ab</sup>	22.16 <sup>a</sup>	19.41 <sup>de</sup>	6.83 <sup>ab</sup>	14.30 <sup>a</sup>	433.15 <sup>d</sup>
T 5°C+O <sub>2</sub> 5%	47.30 <sup>bc</sup>	16.41 <sup>b</sup>	6.84 <sup>a</sup>	22.15 <sup>a</sup>	17.86 <sup>bcd</sup>	6.92 <sup>ab</sup>	14.15 <sup>a</sup>	491.74 <sup>e</sup>

\*) The values followed with different letters in the same column indicate a significant ( $p < 0.05$ )

Table 6 shows the results of the DMRT analysis of the effects of storage temperature and O<sub>2</sub> concentration on the parameters studied separately. It could be clearly observed that, in terms of the effect of O<sub>2</sub> concentration, significant differences only occurred in the F and TSSC parameters. Meanwhile, for the effect of storage temperature, differences occurred in all parameters studied. This indicated that the effect of storage temperature on shallot parameters was much stronger than that of O<sub>2</sub> concentration.

**Table 6.** DMRT results of storage room temperature and O<sub>2</sub> concentration factors

Parameters	Storage Temperature (°C)			O <sub>2</sub> Concentration (%)		
	5	15	28	5	10	21
L	47.6510 <sup>a</sup>	48.4584 <sup>a</sup>	50.7420 <sup>b</sup>	49.2180 <sup>a</sup>	49.4200 <sup>a</sup>	48.2133 <sup>a</sup>
a*	19.0599 <sup>b</sup>	19.5160 <sup>b</sup>	17.3181 <sup>a</sup>	18.4535 <sup>a</sup>	18.4112 <sup>a</sup>	19.0294 <sup>a</sup>
b*	5.2152 <sup>a</sup>	5.8406 <sup>ab</sup>	7.2796 <sup>b</sup>	6.6446 <sup>a</sup>	5.7622 <sup>a</sup>	5.9286 <sup>a</sup>
h*	0.2683 <sup>a</sup>	0.2898 <sup>a</sup>	0.4067 <sup>b</sup>	0.3449 <sup>a</sup>	0.3106 <sup>a</sup>	0.3091 <sup>a</sup>
C*	19.8860 <sup>ab</sup>	20.5023 <sup>b</sup>	19.0635 <sup>a</sup>	19.8144 <sup>a</sup>	19.4888 <sup>a</sup>	20.1490 <sup>a</sup>
$\Delta E$	5.3475 <sup>b</sup>	4.2226 <sup>a</sup>	4.4181 <sup>ab</sup>	4.3719 <sup>a</sup>	4.6173 <sup>a</sup>	4.9991 <sup>a</sup>
F	484.0368 <sup>b</sup>	526.9803 <sup>c</sup>	450.2325 <sup>a</sup>	499.9916 <sup>c</sup>	486.5924 <sup>b</sup>	474.6657 <sup>a</sup>
TSSC	14.2074 <sup>c</sup>	13.9154 <sup>b</sup>	13.4080 <sup>a</sup>	13.7198 <sup>a</sup>	13.8123 <sup>b</sup>	13.9988 <sup>c</sup>

\*) The values followed with different letters in the same column indicate a significant ( $p < 0.05$ )

#### 4. Conclusions

It could be concluded that the values of b\*, h\*,  $\Delta E$ , and TSSC of shallots increased, while the L\*, a\*, C\*, and F decreased during storage in the modified atmosphere condition. In general, the storage temperature at 5°C with 5% O<sub>2</sub> concentration showed the best parameter values. This storage condition had the lowest b\* value, the lowest h\* value, the lowest TSSC value, and the highest F value. While other parameters, such as L, a\*, C\*, and  $\Delta E$ , although not the lowest or highest, were also in low ranges. Therefore, this storage

treatment was concluded as the best storage treatment for shallots. It could also be concluded that the effect of storage temperature on shallot parameters was much stronger than that of O<sub>2</sub> concentration.

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