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Effect of Pre-Cooling and Storage Temperature on the Quality and Shelf Life of Large Red Chili (*Capsicum Annuum* L.)

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ABSTRACT

Large red chili pepper is a high-value horticultural commodity but has a short shelf life, necessitating postharvest quality control through initial cooling and storage temperature management. This study aimed to evaluate the effects of pre-cooling and storage temperature combinations on the quality and shelf life of large red chili pepper to determine optimal conditions that preserve freshness and key quality parameters. The research was conducted from March–May 2025 at the Postharvest Technology Laboratory, Universitas Muslim Indonesia, using the Pilar F1 variety, OPP plastic packaging, and a factorial Completely Randomized Design: pre-cooling by water immersion at 23°C (P1) and 5°C (P2) combined with storage at 5°C (S1), 7°C (S2), 9°C (S3), and room temperature 27–29°C (S4), each with three replications (24 units). The P2S1 combination resulted in the lowest weight loss (≈5.8–5.94%) compared to the highest in P1S4 (≈16.2–16.34%), indicating that low temperature and cold pre-cooling suppress transpiration and respiration. Fruit firmness was generally better maintained at lower temperatures, whereas room temperature accelerated softening (P1: 6.1; P2: 5.9 kg/cm²). The longest shelf life was achieved in P2S1 (14.2 days) and the shortest in P1S4 (4.5 days), consistent with slowed metabolism due to field-heat removal. The highest vitamin C content was also in P2S1 (40.10 mg/100 g) and the lowest in P1S4 (33.80 mg/100 g), corresponding with a lower rate of ascorbic acid oxidation at low temperature. Fruit resilience was strongly correlated with sensory test results, with the best scores in P2S1 (resilience 98.1%; taste score 8.8) and the worst in P1S4 (81.3%; 6.8). Pre-cooling with 5°C cold water followed by storage at 5°C is the most effective postharvest strategy to reduce weight loss and maintain physical and nutritional quality.

INTRODUCTION

The importance of quality control and shelf life for large red chili peppers (*Capsicum Annuum* L.), which are among horticultural commodities with high economic value (Manongko et al., 2023; Prajapati et al., 2025). Large red chili peppers have a relatively short shelf life after harvest, presenting challenges in maintaining their quality during distribution and storage. This decline in quality may be caused by environmental factors such as storage temperature and suboptimal post-harvest cooling processes.

Pre-cooling or initial cooling is one of the postharvest techniques that is effective in slowing down physiological and microbiological processes in horticultural products (Subedi et al., 2022). This technique can rapidly lower the temperature of the fruit after harvest, thereby inhibiting respiration and enzyme activity that cause deterioration (Qureshi et al., 2023). However, the effectiveness of pre-cooling largely depends on the subsequent storage temperature, so selecting the appropriate storage temperature is crucial for maintaining quality and extending the shelf life of large red chili peppers (Dalavi et al., 2025).

Several previous studies have examined the effect of storage temperature on chili quality, but there remains a gap regarding how the combination of pre-cooling techniques and storage temperature variations can simultaneously affect the physical, chemical, and microbiological quality of large red chili peppers (Cheng

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et al., 2023). In addition, most studies have focused more on other chili varieties or have used limited storage temperatures, making comprehensive research necessary on large red chili peppers across a broader temperature range (Duangsi & Krongyut, 2020; Zulfahmi & Jannah, 2022).

The aim of this study is to evaluate the effect of the combination of pre-cooling and storage temperature on the quality and shelf life of large red chili peppers, in order to determine optimal conditions that can preserve freshness, texture, color, moisture content, and other quality parameters during storage (Morgan, 2021). Accordingly, the results of this research are expected to provide practical technical recommendations for farmers and supply chain actors to reduce post-harvest losses and extend the shelf life of the product (Kumar et al., 2025).

This research is important to support food security and increase the added value of large red chili commodities. By understanding the interaction between pre-cooling and storage temperature, it is expected that efficient and economical storage methods can be developed so that chili quality is maintained until it reaches the end consumer (Hong et al., 2023). This research also opens up opportunities for the development of improved postharvest technology in the future (Paul et al., 2024).

MATERIALS AND METHODS

This study was conducted from March to May 2025 at the Postharvest Technology Laboratory, Faculty of Agriculture and Mining Land Bioremediation, Muslim University of Indonesia, Makassar. The primary material used was large red chili fruit of the Pilar F1 variety, with supporting materials such as Oriented Polypropylene (OPP) plastic packaging and labels. Equipment used included a refrigerator, electronic scale, thermometer, penetrometer, storage containers and stationery.

This study employed a Completely Randomized Design (CRD) with a factorial arrangement involving two factors. The first factor is pre-cooling (P), consisting of two levels: P1, immersion in regular water at 23°C, and P2, immersion in cold water at 5°C. The second factor is storage temperature (S), consisting of four levels: S1, temperature of 5°C; S2, temperature of 7°C; S3, temperature of 9°C; and S4, room temperature (27-29°C). The combination of these two factors resulted in eight treatments, each repeated three times, yielding a total of 24 experimental units.

RESULTS AND DISCUSSION

1. Weight Loss

The observations showed that the lowest weight loss (5.94%) was achieved with the combination of cold water pre-cooling and storage at 5°C (P2S1). Conversely, the highest weight loss (16.34%) occurred with the treatment without cooling using regular water and storage at room temperature (P1S4).

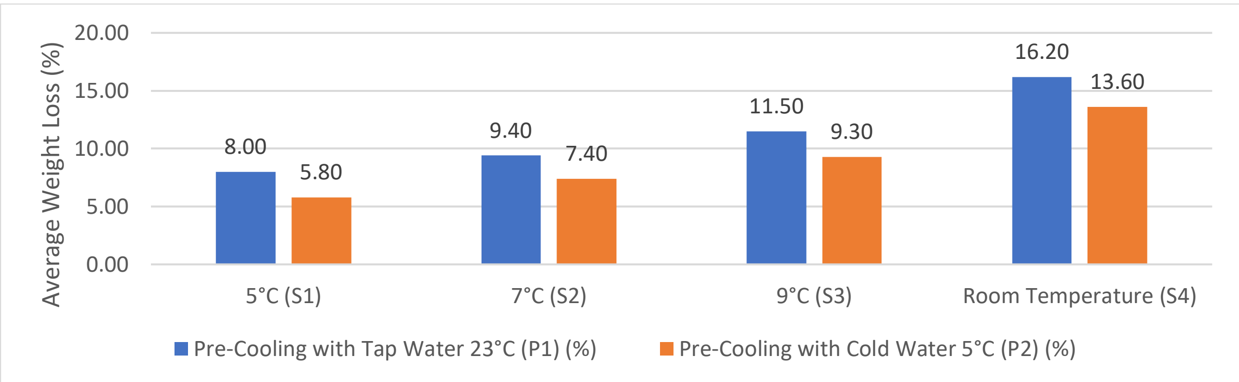

Figure 1. Average weight loss of large red chili peppers in relation to pre-cooling treatment and storage temperature

Based on Figure 1, pre-cooling treatment and storage temperature show an effect on the average fruit weight loss during storage. In general, weight loss tends to increase as storage temperature rises. In addition, fruit treated with pre-cooling using cold water at 5°C (P2) experienced lower weight loss compared to fruit subjected to pre-cooling with regular water at 23°C (P1) at each storage temperature level (Satiti et al., 2025).

At storage temperature 5°C (S1), the P2 treatment resulted in the lowest weight loss at 5.8%, while P1 treatment reached 8.0%. This condition indicates that initial cooling using cold water can suppress weight loss during storage. The same pattern was also observed at 7°C storage (S2), where weight loss in the P2 treatment was 7.4%, lower than the P1 treatment, which reached 9.4% (Shompod et al., 2025).

At 9°C storage (S3), the weight loss increased again to 9.3% in treatment P2 and 11.5% in treatment P1. Meanwhile, the highest weight loss values were recorded during room temperature storage (S4), namely 13.6% in treatment P2 and 16.2% in treatment P1. These results indicate that storage at room temperature accelerates fruit weight loss compared to storage at low temperatures (Kassebi & Korzenszky, 2021).

The increase in weight loss during storage is primarily caused by transpiration and respiration processes that continue after harvest (Firdous, 2021). Transpiration causes water loss from fruit tissues, while respiration results in the use of stored organic materials as an energy source. Both processes proceed more rapidly at higher temperatures, leading to greater fruit weight loss (Ferdousi et al., 2024).

Pre-cooling treatment using 5°C cold water is able to suppress respiration and transpiration rates from the beginning of storage. The reduction of fruit core temperature after harvest helps decrease metabolic activity, thus minimizing water loss(Zainal et al., 2024). Therefore, fruit that receives pre-cooling treatment exhibits lower weight loss compared to fruit without initial cooling using cold water (Zeng et al., 2026).

The results showed that the combination of pre-cooling using cold water at 5°C with storage at 5°C was the most effective treatment in maintaining fruit weight, as indicated by the lowest weight loss value of 5.8% (Hutsol et al., 2024). In contrast, the combination of pre-cooling with regular water at 23°C and storage at room temperature resulted in the highest weight loss of 16.2%. These findings indicate that the application of pre-cooling and storage at low temperatures is an effective postharvest strategy to reduce weight loss and maintain fruit quality during storage (Ivanova et al., 2024).

2. Texture

The texture of large red chili pepper fruit is one of the important physical quality parameters that must be maintained during storage. The effect of pre-cooling treatment and storage temperature variations on fruit firmness needs to be analyzed in order to determine the optimal conditions that can slow down softening and preserve the integrity of fruit tissue during the storage period.

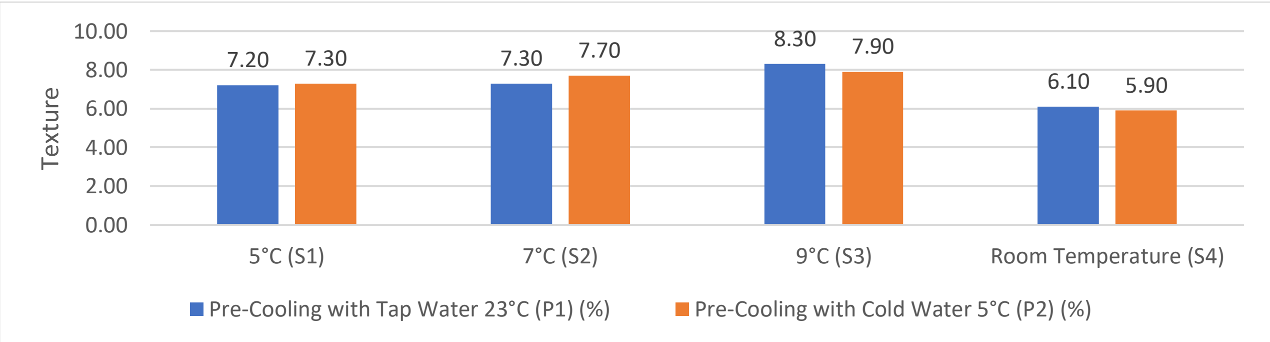

Figure 2. Mean Texture Test of large red chili fruit under pre-cooling treatment and storage temperature

Based on Figure 2, pre-cooling treatment and storage temperature affect fruit firmness during storage. In general, fruit stored at low temperatures is better able to maintain its firmness compared to fruit stored at higher temperatures. In addition, pre-cooling treatment with cold water at 5°C (P2) tends to better preserve fruit firmness compared to pre-cooling with regular water at 23°C (P1) (Chand et al., 2025).

At 5°C storage (S1), the fruit hardness value in treatment P1 was 7.2 kg/cm², while in treatment P2 it was slightly higher at 7.3 kg/cm². An increase in hardness was still observed at 7°C storage (S2), where treatment P2 resulted in a value of 7.7 kg/cm², higher compared to P1 which reached 7.3 kg/cm² (Pathare & Al-Dairi, 2022).

The highest hardness value was obtained at storage at 9°C (S3), namely 8.3 kg/cm² in treatment P1 and 7.9 kg/cm² in treatment P2. This condition indicates that at this temperature, the fruit is still in the texture development phase before undergoing more intensive softening. Conversely, at room temperature storage

(S4), a marked decrease in hardness occurred. Treatment P1 resulted in a hardness of 6.1 kg/cm², while P2 showed 5.9 kg/cm², indicating that storage at room temperature accelerates the fruit softening process (Mthembu et al., 2024).

Changes in firmness during storage are closely related to postharvest physiological processes. The activity of cell wall-degrading enzymes, such as pectin methylesterase (PME), polygalacturonase (PG), and cellulase, causes the pectin in the middle lamella to degrade, thereby weakening the bonds between cells (Xing & Xu, 2022). As a result, fruit texture becomes softer with longer storage durations. The rate of this process generally increases at higher storage temperatures because respiration and metabolism occur more rapidly (Peng et al., 2022).

The application of pre-cooling after harvest plays a role in lowering the initial temperature of the fruit, thereby suppressing respiration and metabolic activity. Initial cooling helps slow the activity of enzymes that cause tissue softening, so that the cellular structure of the fruit remains more stable during storage (Brizzolara et al., 2020). Therefore, fruit that receives pre-cooling treatment is generally able to maintain better texture compared to fruit without initial cooling (Mukama et al., 2020).

The results of the study show that pre-cooling treatment combined with low-temperature storage is able to better maintain fruit firmness compared to storage at room temperature. Although there are variations in firmness values between treatments, this trend indicates that temperature control from the outset of postharvest handling is an important factor in maintaining the physical quality of fruit during storage (Sudhakar Rao & Narayana, 2020). Thus, the application of pre-cooling technology can be an effective strategy to slow tissue softening and extend the shelf life of fruit.

3. Shelf Life

The shelf life of large red chili peppers is an indicator of the effectiveness of postharvest treatments because it reflects the ability to maintain their physical, chemical, and sensory quality during storage. Analysis of pre-cooling and storage temperature is necessary to determine optimal conditions that extend shelf life and maintain the fruit's quality for consumers.

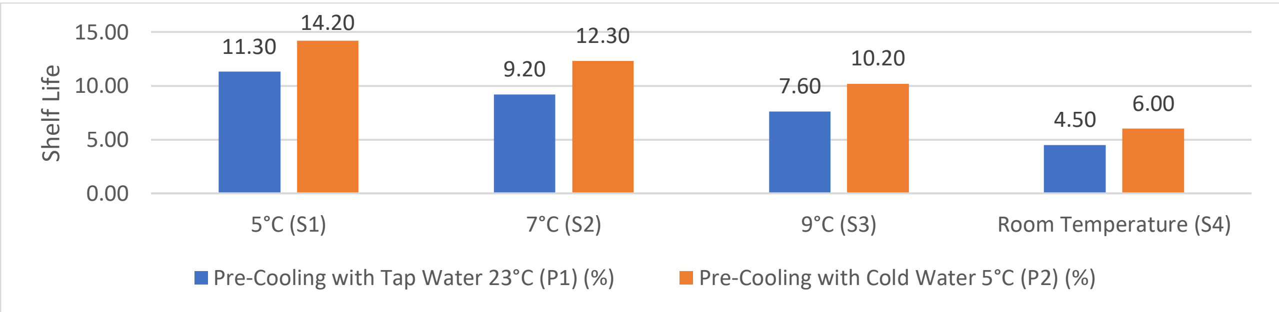

Figure 3. Average shelf life of large red chili fruit according to pre-cooling treatment and storage temperature

Based on Figure 3, pre-cooling treatment and storage temperature affect the shelf life of the fruit. In general, the shelf life tends to be longer at lower storage temperatures compared to higher temperatures. In addition, pre-cooling using cold water at 5°C (P2) is able to maintain a longer shelf life compared to pre-cooling with regular water at 23°C (P1) at each storage temperature (Chaves & Zaritzky, 2018).

At 5°C storage (S1), the P2 treatment resulted in the longest shelf life, namely 14.2 days, while the P1 treatment only reached 11.3 days. These results indicate that initial cooling using cold water is effective in lowering field heat, thereby allowing the fruit's respiration and metabolic rates to be suppressed from the beginning of storage. This condition enables the fruit to maintain its quality for a longer period (Liu et al., 2026).

At 7°C storage (S2), the shelf life of the fruit experienced a slight decrease. The P2 treatment was able to maintain shelf life up to 12.3 days, whereas the P1 treatment only reached 9.2 days. A more pronounced decrease occurred at 9°C storage (S3), with shelf life of 10.2 days for the P2 treatment and 7.6 days for the P1 treatment (Ojurongbe et al., 2022).

The shortest shelf life was obtained with storage at room temperature (S4). Treatment P2 was only able to maintain fruit quality for 6.0 days, while treatment P1 had the lowest shelf life, at 4.5 days. This condition indicates that storage at room temperature accelerates the ripening and senescence processes, causing fruit quality to decline more rapidly compared to storage at low temperatures (Alka et al., 2024).

Differences in shelf life between treatments are closely related to the physiological activity of fruit after harvest. Low storage temperatures can slow down the rate of respiration, transpiration, ethylene production, and enzyme activity involved in ripening and tissue softening processes. Conversely, higher temperatures accelerate metabolic processes, causing food reserves to be depleted more quickly, increasing water loss, softening fruit texture, and speeding up deterioration (Sharma et al., 2020).

Pre-cooling treatment using cold water at 5°C also plays an important role in maintaining shelf life because it can quickly remove field heat before storage (Munson, 2021). Lowering the fruit temperature immediately after harvest can reduce physiological stress and slow down metabolic activity, so the process of quality decline occurs more slowly compared to fruit that is only given pre-cooling using regular water (Hanif et al., 2024).

The results of the study indicate that the combination of pre-cooling using cold water at 5°C and storage at 5°C is the best treatment for extending fruit shelf life, with a shelf life reaching 14.2 days. Conversely, the combination of pre-cooling using regular water at 23°C and storage at room temperature resulted in the shortest shelf life, namely 4.5 days (Qaderi et al., 2022). These findings indicate that the application of pre-cooling followed by storage at low temperatures is an effective postharvest strategy to delay quality deterioration and extend fruit shelf life (Pace & Cefola, 2021).

4. Vitamin C Level

The vitamin C content is important to maintain during the storage of large red chili peppers. The effects of pre-cooling and storage temperature need to be analyzed to determine optimal conditions that minimize nutrient degradation and preserve nutritional quality during storage.

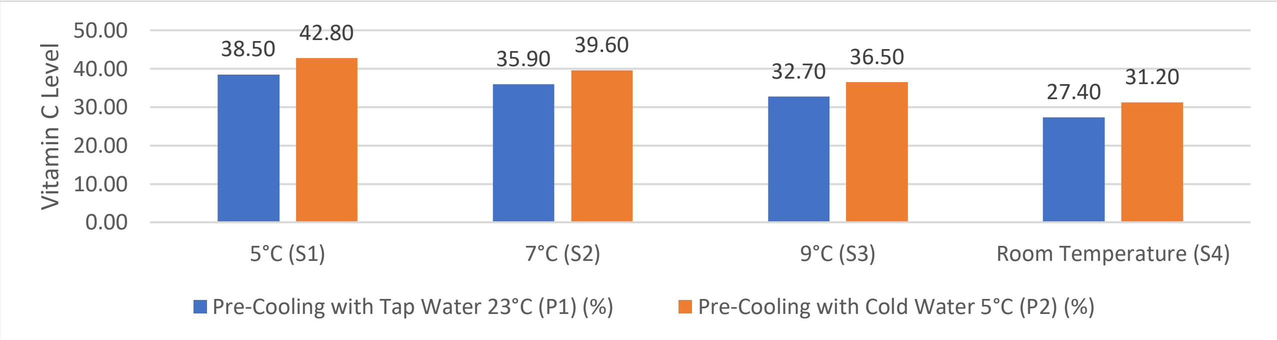

Figure 4. Mean vitamin C content test of large red chili fruit under pre-cooling treatment and storage temperature

Based on Figure 4, pre-cooling treatment and storage temperature affect the vitamin C content of the fruit during storage. In general, vitamin C levels tend to decrease as storage temperature increases. In addition, pre-cooling treatment using cold water at 5°C (P2) is able to preserve vitamin C content better than pre-cooling with regular water at 23°C (P1) at each storage temperature (Amalia et al., 2025).

At 5°C storage (S1), the P2 treatment resulted in the highest vitamin C content at 40.10 mg/100 g, while the P1 treatment was 39.20 mg/100 g. These results indicate that initial cooling using cold water is able to better preserve ascorbic acid content by reducing the fruit's metabolic rate from the onset of storage (Marhiere Akpomie et al., 2020).

At 7°C storage (S2), vitamin C levels began to decrease. Treatment P2 was still able to maintain vitamin C at 38.50 mg/100 g, while treatment P1 maintained 37.80 mg/100 g. A more pronounced decrease occurred at 9°C storage (S3), with vitamin C levels of 36.40 mg/100 g for treatment P2 and 35.90 mg/100 g for treatment P1 (Giannakourou & Taoukis, 2021).

The lowest vitamin C content was found during storage at room temperature (S4). Treatment P2 yielded a vitamin C content of 34.20 mg/100 g, while treatment P1 reached only 33.80 mg/100 g. This condition indicates that storage at room temperature accelerates vitamin C degradation compared to storage at low temperature (Susanti, 2024).

The decline in vitamin C levels during storage is a common process in horticultural commodities. Ascorbic acid is a compound that is easily oxidized, especially when the rate of respiration and enzyme activity increase (Faye et al., 2025). Higher storage temperatures accelerate metabolic activity, resulting in more intensive oxygen consumption and increased activity of enzymes such as ascorbate oxidase (ascorbate oxidase). As a result, vitamin C is oxidized to dehydroascorbate, which then undergoes degradation, so its content continues to decline during storage (Singh & Singh, 2015).

Pre-cooling treatment using cold water at 5°C helps maintain vitamin C levels because it can lower the temperature of the fruit immediately after harvest. This temperature reduction inhibits the respiration rate, reduces oxidative enzyme activity, and slows down the oxidation of ascorbic acid (Serdyuk et al., 2016). Therefore, fruit subjected to pre-cooling treatment retains a higher vitamin C content compared to fruit that is only given pre-cooling with regular water (Shaikh & Shaik, 2026).

The results showed that the combination of pre-cooling using cold water at 5°C with storage at 5°C was the most effective treatment for maintaining vitamin C content, at 40.10 mg/100 g. Conversely, the combination of pre-cooling using regular water at 23°C and storage at room temperature resulted in the lowest vitamin C content, at 33.80 mg/100 g. These findings indicate that the application of pre-cooling followed by low-temperature storage is an effective postharvest strategy for preserving the nutritional quality of fruit, particularly vitamin C content, during storage (Feszterová et al., 2023).

5. Relationship between Fruit Shelf Life and Sensory Evaluation

The relationship between fruit firmness and sensory evaluation is important for assessing the quality of large red chili peppers during storage, since physical firmness affects sensory properties and consumer acceptance. Analysis shows that postharvest treatments maintain fruit quality and flavor.

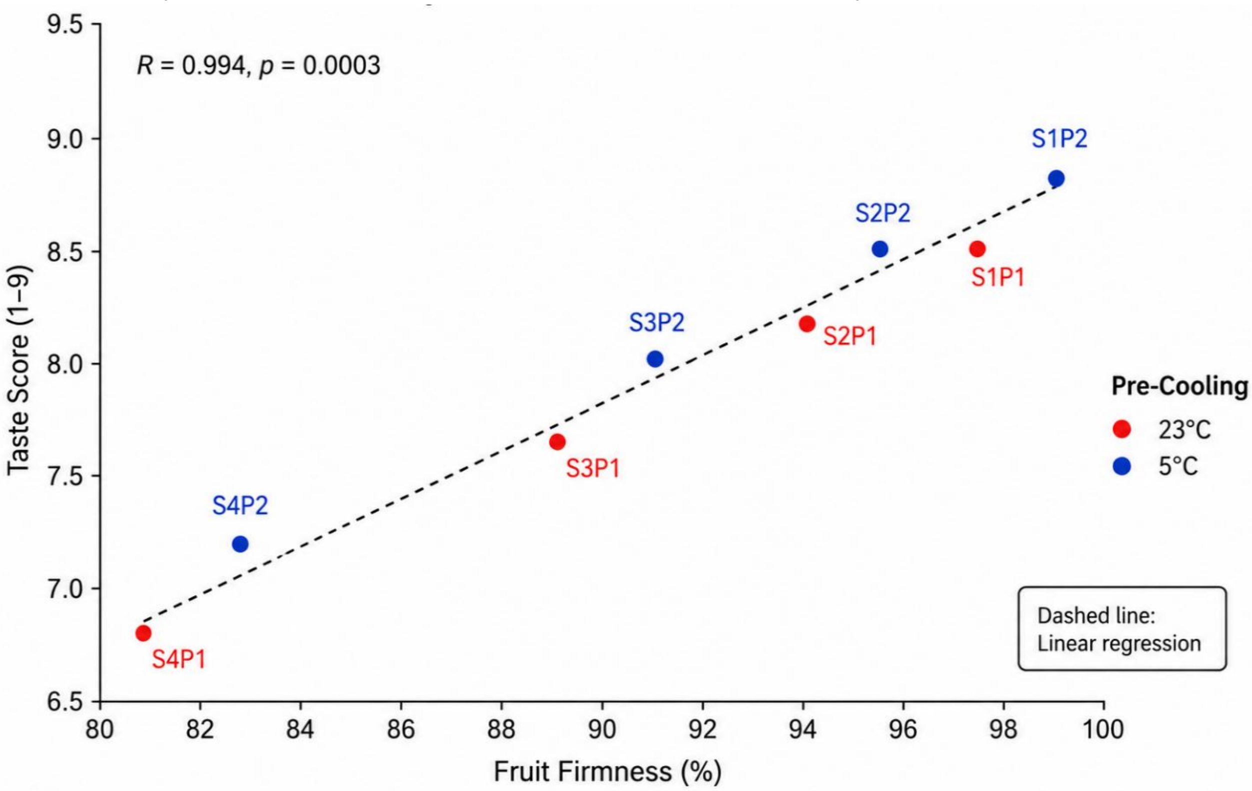

Figure 5. Mean Test of the relationship between fruit shelf life and fruit flavor of large red chili in relation to pre-cooling treatment and storage temperature

Based on Figure 5, there is a very strong positive correlation between fruit shelf life and sensory test scores during storage. The results of the correlation analysis showed a correlation coefficient (R) = 1.00 with a p-value = 0.00084 ($p < 0.05$). This indicates that the higher the shelf life, the higher the sensory score maintained during storage. In other words, the fruit's ability to maintain its physical quality is directly proportional to its ability to maintain its sensory quality (Su et al., 2024).

Pre-cooling treatment using cold water at 5°C (P2) combined with storage at 5°C (S1P2) yielded the best results, with a fruit shelf-life value of 98.1% and a taste test score of 8.8. In contrast, pre-cooling treatment with regular water at 23°C (P1) under the same conditions (S1P1) resulted in a shelf-life value of 96.4% and a taste score of 8.5. These results indicate that initial cooling with cold water is able to maintain fruit quality so that its sensory characteristics remain preferred by the panelists (Shi et al., 2022).

As storage temperature increases, fruit shelf life and taste test scores gradually decline (Lara et al., 2022). At 7°C storage, the S2P2 treatment resulted in a fruit shelf life of 95.2% with a taste score of 8.5, while S2P1 produced a shelf life of 93.5% and a taste score of 8.2. The decrease continued at 9°C storage, where the S3P2 treatment maintained a fruit shelf life of 91.4% with a taste score of 8.0, while S3P1 achieved only 89.6% shelf life with a taste score of 7.7. The lowest fruit shelf life and taste scores were observed at room temperature storage. The S4P2 treatment resulted in a fruit shelf life of 83.2% with a taste score of 7.2, while S4P1 showed only 81.3% shelf life with a taste score of 6.8. These results indicate that room temperature storage accelerates the decline in the physical quality of the fruit, causing taste quality to deteriorate more rapidly compared to storage at lower temperatures (Mditshwa et al., 2020).

The positive relationship between fruit firmness and taste tests is closely related to physiological changes that occur during storage. Fruit that is able to maintain water content, tissue structure, and cell wall integrity will experience lower rates of respiration and transpiration (Hossain et al., 2020). These conditions slow down the process of tissue softening, pectin degradation, and changes in sugar and organic acid composition, all of which play an important role in the development of flavor (Wu at al., 2025). Conversely, reduced fruit firmness due to increased metabolic activity will accelerate senescence, causing the texture to become soft, water content to decrease, and flavor quality to deteriorate (Figueroa et al., 2021).

Pre-cooling treatment using cold water at 5°C has been proven more effective in maintaining fruit shelf life because it is able to remove field heat immediately after harvest (Wang & Zhang, 2020). Lowering the fruit temperature from the beginning of storage suppresses the rate of respiration, ethylene production, and the activity of cell wall-degrading enzymes, so the deterioration process proceeds more slowly. This condition has a direct impact on the preservation of organoleptic characteristics, especially taste, during storage (Johanes, 2019; Latt et al., 2025).

The results of the study indicate that the combination of pre-cooling using cold water at 5°C and storage at 5°C is the most effective treatment for maintaining fruit quality. This treatment resulted in the highest fruit resistance (98.1%) as well as the highest taste test score (8.8). In contrast, the combination of pre-cooling with regular water at 23°C and storage at room temperature produced the lowest fruit resistance (81.3%) and taste test score (6.8). These findings confirm that increased fruit resistance during storage directly contributes to the preservation of taste quality, as evidenced by a very strong positive correlation. Thus, the application of pre-cooling technology followed by low-temperature storage can be an effective postharvest strategy for maintaining both the physical and sensory quality of fruit during storage (Büchele et al., 2023; Khan et al., 2018).

CONCLUSIONS

The combination of pre-cooling using cold water at 5°C followed by storage at 5°C is the most effective postharvest treatment to maintain the quality and extend the shelf life of large red chili. This treatment minimizes weight loss, preserves fruit texture and vitamin C content, and sustains both physical and sensory quality during storage. Applying this strategy can reduce postharvest losses and enhance the marketability of the chili.

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