Quality and shelf-life extension of vegetables using precision control storage system

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Abstract. Post harvest loss is one of the factors causing the reduction in the amount of food available for the future. This research is to study the change of the weight, visual, sensory and total soluble solid of the butterhead lettuce with IoT storage chamber with different treatments (i.e T1, T2, and T3). At the final day of storage period, there are no significant differences on weight loss between T2 and T3, and between T1 and T2. The visual quality of the butterhead lettuce significantly decreased during the storage period. The overall acceptability and sweetness of T1 are the highest; T3 has the better aroma and texture; the appearance was not significantly different among all the treatments. For the total soluble solid, the content for all treatments were significantly increased when the storage period progressed. T1 is the most recommended treatment as it had extended one week of storage period and able to retain better sweet taste and appearance compared to the other treatments.

1 Introduction

In 2022, Fahy [1] reported food security is an individual able to access an adequate nutritious food amount that meets the dietary needs and food preferences for healthy life. The worldwide population is expected to reach 9 billion by 2050, and food production needs to increase by 70% to meet the global demand [2]. However, the higher the postharvest loss, the lower the food production. The factors that cause the postharvest loss include improper postharvest handling, supply chain logistics, improper storage, lack of skills and technology [3]. The water content in the leafy vegetables is high which causes the leafy vegetables to be highly perishable, leading to the leafy vegetables to be spoiled easily [4]. The quality loss of the leafy vegetables can be determined by the weight loss, appearance, colour, total soluble solid, titratable acidity, antioxidants content and microbial count [5]. Leafy vegetables stored at ambient temperature cause dehydration and wilting to occur, however the leafy vegetables stored under 0°C-2°C, the freshness and quality can be maintained. The insufficient

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electricity and water supply in developing countries, which do not have a favourable storage environment, thus caused the vegetables to spoil.

In the developing country, the number of postharvest losses is 40% [6]. Therefore, developing the IoT storage chamber that can precisely control the temperature, humidity, and carbon dioxide, and has good ventilation is hoped to reduce postharvest losses and increase the amount of food needed for the world population. *Lactuca sativa* (lettuce) was chosen as the sample because lettuce can be consumed raw and the demand is high, thus the safety of the lettuce is the utmost concern for the consumer. The objectives of this research are to design and set up the automated IoT-based control system to precisely control the temperature and monitor the humidity of the storage chamber. Besides, the effects of the different misting system installed in the IoT chamber on the postharvest shelf life, sensory properties, and total soluble solids of the lettuce are compared.

2 Methodology

2.1 IoT storage chamber

Size of the storage chamber (width × length × height) is 45.5 cm × 67.5 cm × 43.0 cm. As shown in Figure 1, the components used to develop the storage chamber are Raspberry Pi with Raspberry Pi OS installed, 4-channel 5V relay, 150W DC boost convertor, Peltier cooler assembly, water pump, DHT22 temperature and humidity sensor, power adapter, misting nozzles and water tanks (Figure 2). The internal temperature of the chamber was maintained by the Peltier cooler assembly. The assembly consists of Peltier module, heatsinks, and fans, as the Peltier module was built in between large heat dissipating heatsink and small cold dissipating heatsink. The Peltier module has two sides, cooling effect on one side, and heat effect on another side. The hot side was in contact with the large heat dissipating heatsink and a large cooling fan is attached to the heatsink to dissipate the heat. In contrast, the cold side was in contact with the small cold dissipating heatsink and a small blower fan is attached to the heatsink to blow air through the heatsink and produce low temperature air. Therefore, the cooling fan was installed outside of the chamber and the blower fan was installed inside of the chamber. As the preset condition of the Peltier cooler, it will switch off when the temperature is below 15°C and switch on above 15°C. In Figure 3, the misting system of the chamber was installed to spray water to the butterhead lettuce, which helps to maintain the humidity in the chamber between 70-80%. The DHT 22 temperature and humidity sensor (in Figure 4) was used to detect the real-time reading in the chamber and then the Raspberry Pi was connected to Wi-Fi and obtained the real-time reading of temperature and humidity every two seconds. There are three treatments in this study, such as treatment 1 is the IoT storage chamber with tap water misting system and Peltier cooler (T1); treatment 2 is the IoT storage chamber with Peltier cooler only (T2); treatment 3 is the IoT storage chamber without Peltier cooler and misting system (T3). In each chamber, two butterhead lettuces weighed within 100 g to 150 g were placed into the chamber.

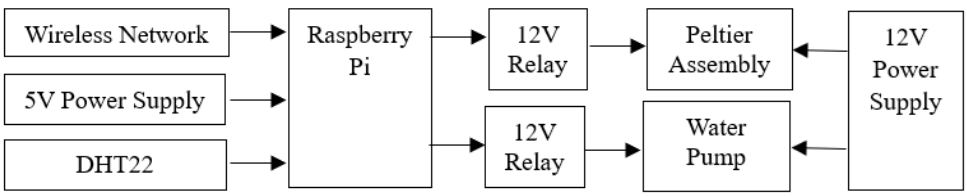

Fig. 1. System Architecture of IoT storage chamber.

Fig. 2. The back of the storage chamber.

Fig. 3. Lid of storage chamber with misting system.

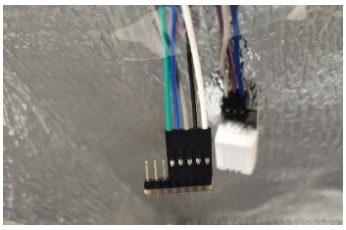

Fig. 4 Humidity and temperature sensors were used in this work.

2.2 Weight loss

The initial weight of the butterhead lettuce (Day 0) was taken before placing it in the storage chamber. The weight of the butterhead lettuce was measured every day. The final weight of the butterhead lettuce was measured when the butterhead lettuce was not suitable to be consumed. The percentage of weight loss was calculated by using the formula given.

$$Percentage\ of\ weight\ loss\ (\%) = \frac{(Initial\ weight - Final\ weight)}{Initial\ weight} \times 100\% \quad (1)$$

2.3 Visual quality scoring

The visual of the each butterhead lettuce was observed every day. Based on the rating and description in Table 1, the visuals were measured by using a 5-point hedonic scale [7].

Table 1. The rating and appearance description of the butterhead lettuce.

Rating	Description of the Appearance
5: Excellent	Butterhead lettuce was characterized by its freshness with no defect, green in colour, and turgid.
4: Good	Butterhead lettuce was characterized by its freshness with small defect, turgid, and green in colour. In addition, the defect size of the leaves was also measured to be less than 0.5 cm.
3: Fair	Butterhead lettuce was characterized by its slightly wilt, slightly browning, and dull green colour. Also, the defect size of the leaves is more than 0.5 cm.

2: Slightly defect	Butterhead lettuce was characterized by its wilt, moderate browning, and dull green colour. Moreover, the defect size of the leaves is more than 1.0 cm.
1:Extremely defect	Butterhead lettuce was characterized by its severe wilt, severe browning, and severe loss of green colour. Next, the butterhead lettuce is not suitable to be marketed.

2.4 Sensory evaluation

The sensory evaluation was conducted on day 2 of the storage period. There are 50 untrained panelists involved in the sensory evaluation. A 9-point hedonic scale was used to determine the butterhead lettuce in terms of appearance, aroma, sweetness, texture, and overall acceptability. The scoring is from 1 to 9, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely [8].

2.5 Total soluble solids

A 10 g of representative butterhead lettuce was sampled cut into small pieces and added into the mortar. An 8 mL of distilled water was added into the mortar to help to obtain the lettuce juice. The total soluble solid was measured by using a refractometer and expressed in the terms of °Brix [9].

2.6 Statistical analysis

SPSS software (version 29) was used to conduct the data analysis. This research was completely randomized design, and all the tests were duplicated. Data was presented as mean ± standard deviation (SD). One-way ANOVA was used to analyze the factors, and the Tukey's test was used to calculate the significant difference of multiple means ($p<0.05$).

3 Results and discussion

3.1 Weight loss

According to the results in Table 2, the final day of storage for T1 is day 12; T2 is day 6; and T3 is day 3, respectively. On the final day, all the samples had mold growth on the butterhead lettuce. There are significant differences ($p<0.05$) for butterhead lettuce weight loss for T1. Temperature and humidity are the factors that can affect the appearance, weight, and cause the growth of microbials. As the temperature decreases, the respiration of the sample can be reduced. As the respiration rate decreases, the appearance and weight loss will decrease [10]. As relative humidity increases, which means the surroundings are moist. The exchange of water between the butterhead lettuce and surrounding was reduced, thus leading to the reduction of weight loss [11].

Table 2. Percentage of weight loss of the butterhead lettuce.

Treatment	Percentage of Weight Loss (%) / Day		
	3	6	12
1	29.76 ± 9.62^{a}	40.36 ± 14.29^{a}	80.69 ± 13.00^{b}
2	29.55 ± 1.15^{a}	45.77 ± 1.25^{ba}	-
3	16.96 ± 3.32^{a}	-	-

Data are presented as mean ± standard deviation (SD) (n=2).
$^{a-b}$: Using Tukey's test, data with same superscript are not significantly different ($p>0.05$).

3.2 Visual quality scoring

Based on the findings in Table 3, T1 had better visual quality rating along day 3 and day 6 by comparing with the T2 and T3. The sample in T1 is green in colour, and the size reduction is very small on day 3. On day 6, the colour of leaves in T2 have browning, and mould growth, whereas the leaves from T1 turned yellow, and the outermost leaves started to dry. On day 12, the visual quality score of the butterhead lettuce samples in the T1 decreased because the leaves became dry and turned browning. The temperature between 25°C to 30°C and humidity above 55% are the favourable conditions for the growth of the mould and fungi [12]. The temperature and humidity of the chamber was maintained between 28.1°C to 29.6°C, and 99.2% to 100% (Table 4), thus the growth of moulds was observed. Although the high temperature causes the respiration rate to increase, the high humidity causes the transpiration rate to slow down, thus the water loss of the butterhead lettuce slows down. Other than weight loss, the appearance of the sample can be affected by temperature and humidity. As the respiration and transpiration rate increases, the deterioration rate will increase, which the appearance of butterhead lettuce becomes dry and the colour of the leaves turn yellowish or browning.

Table 3. Visual quality rating of the butterhead lettuce.

Treatment	Visual Rating / Day		
	3	6	12
1	4.00 ± 0.00^{a}	2.50 ± 0.71^{b}	1.00 ± 0.00^{c}
2	3.00 ± 0.00^{ba}	2.00 ± 0.00^{cb}	-
3	3.00 ± 0.00^{ba}	-	-

Data are presented as mean ± standard deviation (SD) (n=2).
[a-b]: Using Tukey's test, data with same superscript are not significantly different ($p>0.05$).

Table 4. Average temperature and humidity of T3 storage chamber.

Day	0	1	2	3
Temperature (°C)	28.1	29.6	29.1	29.1
Humidity (%)	99.2	100.00	100.0	100.0

3.3 Sensory evaluation

Based on the data in Table 5, T1 has the highest scoring for sweetness among the samples. In terms of appearance, T1 and T3 have similar scoring whereas T2 has the best appearance. However, in terms aroma and texture, T3 has the highest mean score, followed by T1 and T2. The overall acceptability that has the highest mean score is T1, then followed by T3 and T2. By comparing T2 and T3, both treatments do not have misting system, which after the sample loss of water, do not have extra misting. However, T2 has a Peltier cooler, the water vapor and hot temperature will be removed out from the chamber, whereas T3 is an enclosed chamber, no ventilation. Thus, the high humidity in T3 reduces the loss of weight and moisture, therefore the crunchiness (texture) and the aroma of the butterhead lettuce can be maintained.

Table 5. Mean scores of each sensory attributes for different treatments.

Treatment	Sensory Mean Score				
	Appearance	Aroma	Sweetness	Texture	Overall Acceptability
1	6.98 ± 1.36^{a}	6.34 ± 1.60^{a}	5.98 ± 2.00^{a}	6.34 ± 1.81^{a}	6.54 ± 1.67^{a}
2	7.02 ± 1.35^{a}	6.10 ± 1.42^{a}	5.62 ± 2.11^{a}	6.02 ± 1.70^{a}	6.26 ± 1.85^{a}
3	6.98 ± 1.25^{a}	6.52 ± 1.30^{a}	5.88 ± 1.97^{a}	6.68 ± 1.38^{a}	6.50 ± 1.68^{a}

Data are presented as mean ± standard deviation (SD) (n=50).
[a]: Using Tukey's test, data with same superscript are not significantly different (p>0.05).

3.4 Total soluble solids

The total soluble solids of butterhead lettuce are summarized in Table 6. The total soluble solids increased throughout the storage period for sample in T1 and T3, except sample in T2, the total soluble solids decreased on day 3 and increased on the final day. There was no significant difference (p>0.05) for T1. The use of misting system in T1 can help to maintain the temperature and humidity between 22°C to 24.5°C, and 66.3% to 71.6% (Table 7), thus the freshness was retained, prolong the shelf life, and reducing the weight loss. As the respiration rate of the butterhead lettuce slows down, the ripening process decreases as well, thus slowing down the breakdown of sugar [13].

Table 6. Total soluble solids of the butterhead lettuce.

Treatment	Total soluble solids / Day		
	0	3	6
1	1.45 ± 0.21^{ba}	1.53 ± 0.11^{ba}	1.55 ± 0.07^{ba}
2	1.65 ± 0.21^{ba}	1.45 ± 0.00^{ba}	1.95 ± 0.07^{a}
3	1.05 ± 0.35^{b}	1.40 ± 0.28^{ba}	-

Data are presented as mean ± standard deviation (SD) (n=2).
[a-b]: Using Tukey's test, data with same superscript are not significantly different (p>0.05).

Table 7. Average temperature and humidity of T1 storage chamber.

Day	0	1	2	3	4	5	6	7	8	9
Temperature (°C)	22.0	24.0	23.6	24.4	24.0	22.0	24.3	24.5	23.5	23.2
Humidity (%)	71.6	71.6	70.6	71.5	70.1	67.3	70.7	68.8	67.1	66.3

4 Conclusion

Based on the result obtained, the different treatment of the storage chamber has a significant effect on the weight, visual quality, sensory, and titratable acidity of butterhead lettuce. The weight loss of the butterhead lettuce increased when the storage period progressed, where the visual quality of the butterhead lettuce decreased. According to degree of liking, sample in T3 have better texture and aroma, but sample in T1 was sweeter and the overall acceptability was the highest. The total soluble solids of the butterhead lettuce increased significantly during the storage period. The most recommended treatment is T1 because the storage period can be extended for at least one-week, better sweetness and appearance. However, the storage chamber requires electricity supply through the electrical socket or plug point. Therefore, the storage chamber is unable to be operated without the power supply. In the future, solar panels can be installed on the cover of the storage chamber to generate sustainable power source for the operation of the chamber.

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References

1. A. Fahy, What is food security? (2022). https://concernusa.org/news/what-is-food-security/#:~:text=Food%20security%20is%20the%20measure,for%20active%20and%20healthy%20lifestyles.

2. Food and Agriculture Organization, Global goals towards 2050, (2009). https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.
3. D. Kumar and P. Kalita, Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, **6** (2017). https://doi.org/10.3390%2Ffoods6010008
4. M. Petruzzello. Vegetables, (2024). https://www.britannica.com/topic/vegetable
5. World Food Programme, Post-harvest loss reduction, (2022). https://innovation.wfp.org/project/post-harvest-loss-prevention#:~:text=In%20some%20developing%20countries%2C%20smallholder,produce%20later%20at%20increased%20prices
6. O.F. Etefa, S.F. Forsido and M.T, Kebede, Postharvest loss, causes, and handling practices of fruits and vegetables in Ethiopia: Scoping Review. J. Horticultural Research, **30** (2022). http://dx.doi.org/10.2478/johr-2022-0002
7. C.E. Belisle, S.A. Sargent, J.K. Brecht, G.V. Sandoya and C.A. Sims, Accelerated shelf-life testing to predict quality loss in Romaine-type lettuce. HortTech., **31**, 490-499, (2021). https://doi.org/10.21273/HORTTECH04812-21
8. A. Gámbaro and M.B. McSweeney, Chapter Eight-Sensory methods applied to the development of probiotic and prebiotic foods. Adv. in Food and Nutr. Research, **94**, 295-337, (2020). https://doi.org/10.1016/bs.afnr.2020.06.006
9. B. Mitcham, M. Cantwell and A. Kader, Methods for determining quality of fresh commodities, Perishables Handling Newsletters, **85**, (2003). https://www.researchgate.net/publication/265032033_Methods_for_Determining_Quality_of_Fresh_Commodities
10. V. Kiaya. Post-harvest losses and strategies to reduce them. Technical paper on Post-Harvest Losses, (2014). https://www.actioncontrelafaim.org/wp-content/uploads/2018/01/technical_paper_phl__.pdf
11. P.V., Mahajan, F.A.R. Oliveria and I. Macedo, Effect of temperature and humidity on the transpiration rate of the transpiration rate of the whole mushrooms. J. Food Engineering, **84**, 281-288, (2008). https://doi.org/10.1016/j.jfoodeng.2007.05.021
12. My Pure Environment, How much moisture does mold need to grow? (2021). https://www.mypureenvironment.com/post/how-much-moisture-does-mold-need-to-grow/#:~:text=Mold%20grows%20fastest%20between%2077,dormant%2C%20which%20limits%20spore%20production.
13. R. Mishra and A. Kar, Effect of storage on the physicochemical and flavour attributes of two cultivars of strawberry cultivated in Northern India. The Sci. World J., **2014** (2014). https://doi.org/10.1155/2014/794926