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Effect of Maturity Stages on the Quality of Cold Storage Iceberg Lettuce (*Lactuca sativa* var. capitate) for Export

Tolcha Techane Alemu[1,2] & Vu Thi Kim Oanh[1*]

[1]Faculty of Food Science and Technology, Vietnam National University of Agriculture, Hanoi 131000, Vietnam

[2]College of Agriculture and Veterinary Medicine, Jimma University, Jimma 00000, Ethiopia

Abstract

Iceberg lettuce is one of the most important vegetables economically and nutritionally, but its perishable nature poses challenges for storage and long-distance transportation. This study investigated the effect of maturity stages on the quality of iceberg lettuce for export under cold storage conditions. A completely randomized design with three replications was used to evaluate four maturity stages based on days after planting (DAP): 52, 55, 58, and 61 DAP. The lettuce heads were stored at 3±2^{o}C and a 95% relative humidity, and quality parameters were analyzed every three days until the end of storage. Sensory properties, weight loss, color change, total soluble solids, total phenolics, and decay rates were evaluated. The results showed that maturity stages significantly (P <0.05) affected the quality attributes of iceberg lettuce and that harvesting at the optimal stage is very important. Findings from this study confirmed that the quality parameters were preserved for the 58 DAP samples throughout the storage time. They indicated that at three weeks of storage time, the lowest weight loss (5.9%), color change (14.1), and decay rate (8.3%), and the highest sensory analysis (5 scores) and appearance were shown by the 58 DAP maturity stage lettuce. Therefore, harvesting iceberg lettuce at 58 DAP is recommended for long-distance exportation.

Keywords

Iceberg lettuce, maturity stages, quality

Introduction

Iceberg lettuce (*Lactuca sativa* var. capitata), a member of the Asteraceae family, is a widely consumed fresh perishable crop produced on a global scale (Meena & Kulakarni, 2022).Recognized for its nutritional and phytochemical properties, iceberg lettuce holds a prominent place among vegetables. However, its short shelf-life is a result of its high moisture content, which stands at about 95%, and

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Correspondence to
vtkoanh@vnua.edu.vn

its rapid biological and physiological reactions (Kim *et al*., 2016). In the realm of agricultural production, iceberg lettuce plays a pivotal role, serving as a cornerstone of agricultural economies. Notably, in countries such as Vietnam, it is considered a high-value economic crop (Binh *et al*., 2014). Furthermore, its export potential is significant, boasting competitive advantages in international markets.

Maturity is the stage of growth that is of interest to consumers, and harvesting vegetables at the appropriate time is the most important factor for the determination of general quality and shelf life (Tilahun *et al*., 2011). Vegetables picked either too early or too late have shorter shelf lives than vegetables picked at the proper maturity stage (Gil *et al.*, 2012). Harvesting lettuce at an inappropriate stage of maturity can also have a detrimental impact on its quality, so harvesting time remains a pivotal consideration in post-harvest handling (Rizzolo & Zerbini, 2012). When iceberg lettuce is harvested at improper maturity it becomes susceptible to both mechanical damage and physiological disorders, leading to a fast degradation in quality. Therefore, the maturity stages affect the quality of vegetables, particularly if the vegetables are harvested at an immature stage of maturity they can become susceptible to shrivelling and mechanical damage, develop poor sensory qualities, and the color, weight, total soluble solids (TSS; good flavor), and phenolics can be negatively affected resulting in a loss of consumer confidence during marketing (Chutichud *et al*., 2011; Quamruzzaman *et al*., 2022). According to Gil *et al*. (2012), if iceberg lettuce is harvested after reaching the mature stage, it begins developing a bitter flavor and its color changes due to enzymatic activity. Kang *et al*. (2008) reported that the decay rate is higher in immature lettuce than mature and over-mature ones.

Harvesting vegetables at either an immature or over-mature stage can also result in substantial post-harvest losses and poses challenges for expedited exportation due to elevated air freight expenses. Iceberg lettuce, in particular, experiences a decline in its quality and physicochemical attributes even before it reaches domestic and international markets via marine transport, leading to substantial market quality deterioration (Patil *et al.*, 2017; Ikegaya *et al*., 2019). Beyond the quality aspect, vegetables harvested at inappropriate maturities complicate various post-harvest handling procedures such as packaging, transportation, and storage, which result in post-harvest losses ranging from 20% to 44% (Faqeerzada *et al*., 2018). As reported by Eriksson *et al*. (2012), iceberg lettuce ranks as the third most wasted crop during exportation, primarily due to the issue of harvesting at incorrect maturity stages.

Determining the ideal maturity stage presents a considerable challenge, and the passage of days after planting emerges as a critical factor in identifying this stage. This study provides basic information and insight for growers, consumers, and traders to reduce the post-harvest loss of vegetables like iceberg lettuce with a focus on the harvesting time for export purposes. It also contributes to the development of the export-oriented lettuce industry in Vietnam. Consequently, pinpointing the optimal time for harvesting vegetables is pivotal in ensuring that iceberg lettuce possesses superior quality, extended marketability, and an enhanced shelf-life. Nevertheless, knowledge pertaining to how the maturity stages of vegetables affects the post-harvest quality of iceberg lettuce designated for export remains limited. Therefore, the primary objective of this study was to ascertain the optimal maturity stage for cold-stored iceberg lettuce, with the aim of enhancing its quality and prolonging its marketability for export via sea freight, taking into account the number of days after planting.

Materials and Methods

Plant materials

Freshly harvested iceberg lettuce heads variety “Saula” (produced by the Enza Company) were obtained from a farm located in Moc Chau district, Son La province, Vietnam. After harvest, the samples were immediately transported to the Laboratory of Post-harvest Technology by wrapping them with low-density polyethylene (LDPE) and packing them inside carton boxes glued with polyethylene. Samples were then manually cleaned by using tissues, and damaged leaves were manually removed. Thereafter, cleaned samples free from any damage or defects were kept in a cool chamber storage at 3 ± 2°C with a 95% relative humidity.

Experimental design

The experiment was laid out in a complete randomize design (CRD) using the maturity stages as factors with four levels. Lettuce heads were harvested at different maturity stages according to days after planting (DAP): stage I (52 DAP), stage II (55 DAP), stage III (58 DAP), and stage IV (61 DAP). The levels were selected according to Chutichudet *et al*. (2011) for determination of the optimal maturity stage based on days after planting. Lettuce heads were packed in carton boxes with a layer of LDPE film on the inside of the boxes and stored in a cooling chamber at 3 ± 2°C and 95% relative humidity. Quality parameters were analyzed every three days until they were no longer valid. Each parameter was replicated three times.

Determination of quality parameters

Sensory evaluation

The sensory analyses of the iceberg lettuce were carried out following the procedures of Aguero *et al.* (2011) and Belisle *et al.* (2021). Then, visual qualities, namely color, taste, internal and external morphology, and freshness, of the iceberg lettuce were assessed and scored following a 9-point rating scale with 9: excellent, 7: good, 5: fair, 3: poor, and 1: extremely poor. The average of these scale points was used as an estimation of the overall visual quality. A score of 5 was considered as the threshold for marketability (Vitti *et al.*, 2005).

Weight loss

The weight loss of the iceberg lettuce was determined using the methods described by Lee & Chandra (2018). Seven heads per maturity level were used for weight loss determination. The initial and final weights were measured and then the weight loss (%) was calculated using the formula:

$$Weight\ loss\ (\%) = \frac{Initial\ weight\ (g) - Final\ weight(g)}{Initial\ fresh\ Weight(g)} \times 100$$

Color

The color change of the iceberg lettuce was determined by using a chroma meter (CR 400-410 Japan) according to Lee & Chandra (2018). It was calibrated using a standard white plate (Y= 81.8, × =0.3215, y =0.3392). Three samples per replication were used and three readings from the left, middle, and right parts of a leaf were taken. Color change was quantified as the $L*$, $a*$, $b*$ color space where $L*$, *light,_*$a*$ indicated the green and red colors and b* indicated the yellow and blue colors.

From the values of $L*$, $a*$, $b*$, the total color difference ($\Delta E*$) was also calculated using the formula:

$$\Delta E* = \sqrt{(\mathrm{L}o*-\mathrm{L}*)^2 + (\mathrm{ao}*-\mathrm{a}*)^2 + (\mathrm{bo}*-\mathrm{b}*)^2}$$

where L_0*, a_0*, b_0* represent the values after harvest and L*, a*, b* indicate a reading on any evaluation day.

Total soluble solids (TSS)

The total soluble solids were determined by using a digital refractometer (PAL-1, LRO3*2 Tokyo, Japan) according to Vargas-Arcila *et al*. (2017).

Total phenolic content (TPCs)

The TPC was determined by Folin-Ciocalteu reagent (FCR) using gallic acid as the standard according to the methods of Singleton (1999). Five grams (5 g) of iceberg lettuce was extracted three times with 25 mL of 99.8% methanol by grinding using a mortar and pestle. Then, the extract was homogenized by a homogenizer (IKA, T25 digital ULTRA-TURRAX) and centrifuged for 10 min at 7000 rpm at 4°C (Centrifuge 5810R, Eppendorf, Hamburg, Germany). Gallic acid solution served as the standard for preparing the calibration curve and was prepared with a 1 mg mL^{-1} ratio. Various concentrations of gallic acid solutions in methanol (0, 10, 20, 30, 40, and 50 µg mL^{-1}) were prepared. Each sample extract (1mL) was added to a test tube and 10% 2 N Folin-Ciocalteu reagent (5mL) was added. Finally, 7% Na_2CO_3 (4mL) was added to the solution to make a final volume of 10mL and mixed well. The absorbance was measured by using a UV-spectrophotometer (UV-1900i-Shimadzu Kyoto, Japan) at a wavelength of 765nm. The total phenolic content of the extracts was expressed as mg gallic acid equivalents (GAE) per gram of sample and calculated by the following formula:

$$\text{TPC (mg GAE/g FW)} = \frac{c*v}{m}$$

where TPC is the total phenolic content in mg GAE/g FW, c is the concentration of gallic acid from the calibration curve in mgmL-1 , v is the volume of the extract in mL, and m is the mass of the extract in grams.

Decay rate

The amount of iceberg lettuce damaged during cold storage was calculated according to the methods of Singh *et al.* (2014) with the formula:

$$\text{Percentage of decayed rates} = \frac{\text{Number of deteriorated}}{\text{Total number of samples}} * 100$$

Statistical analysis

Data were analyzed by using one-way analysis of variance (ANOVA) using Minitab 16 statistical software and MS Excel software. Mean comparisons were done by using Tukey's multiple comparison test to determine the significance of differences among the treatments at a 95% confidence level. Results were given as mean ± SE (standard error). Each mean was the average of three observations.

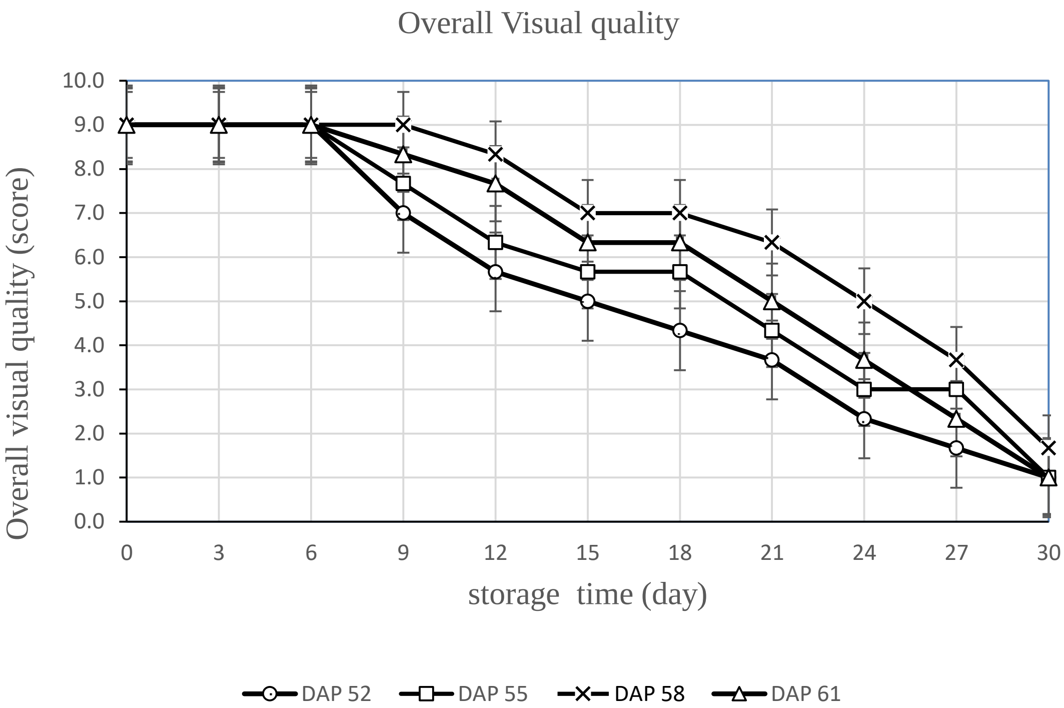
Results and Discussion

Sensory quality

The sensory properties of iceberg lettuce, namely color, taste, morphology (both internal and external), freshness, and overall visual quality (OVQ), were examined. According to **Figure 1**, the OVQ of iceberg lettuce remained constant across all maturity stages until the sixth day of storage, displaying no significant differences (P >0.05). However, following the sixth day of storage, the OVQ experienced a decrease across all stages, except for the lettuce harvested at 58 DAP, which did not exhibit a decrease in OVQ until after nine days. This decrease in OVQ could be attributed to reduced freshness resulting from moisture loss and discoloration triggered by enzymatic reactions. This observation agrees with the findings of Farahanian *et al.* (2023), who reached a similar conclusion. Furthermore, the overall acceptability of the lettuce decreased due to the formation of condensation inside the packaging material, leading to deterioration and rendering the samples unacceptable for commercial markets. Similarly, Lee & Chandra (2018), also reported that the overall visual quality of lettuce decreased during various storage periods.

The decline in the OVQ may have also been attributed to the negative impacts on both the external and internal components of lettuce, derived from defects and increased respiration rates during storage. Aguero *et al.* (2011) and Hunter *et al.* (2017) reported similar observations. Similarly, the research conducted by Gil *et al.* (2012) supports our findings, as it indicated that immature vegetables experience greater water loss, resulting in wrinkling and diminished flavor quality. Quamruzzaman *et al.* (2022) underscored the importance of harvesting vegetables and fruits at appropriate stages of maturity, as their study suggested that immature produce is prone to shrivelling, mechanical damage, and developing poor color, flavor, and taste resulting in a loss of consumer confidence.

Our results, as shown in **Figure 1**, revealed that throughout all the storage periods, lettuces harvested at 52 DAP exhibited the lowest OVQ, whereas samples at 58 DAP displayed the highest OVQ. This difference could be attributed to the fact that the lettuces harvested at 58 DAP reached their optimal maturity, allowing them to maintain a superior appearance, and have lower rates of wilting and shrivelling, fewer defects, and reduced decay, all while preserving a higher level of freshness compared to the other maturity stages. These findings are consistent with those of Quamruzzaman *et al.* (2022), who emphasized the significance of optimum maturity indices in influencing the growth and quality of high-value vegetables.



Note: Vertical bars represent the standard error of the mean of three replications.

Figure 1. Effect of maturity stage on the overall visual quality of iceberg lettuce during cold storage

Importantly, it is worth noting that after 24 days of storage, samples harvested at 61 DAP demonstrated a lower OVQ compared to those harvested at 55 DAP (P <0.05). This difference could be linked to the inclination of lettuce harvested at a later stage to develop russet spots, as well as an increased susceptibility to enzymatic browning due to the breakdown of cellular compartmentalization and membrane integrity. In the end, as the evaluation period concluded, samples harvested at 58 DAP consistently exhibited a significantly higher OVQ (P <0.05). Overall, the results of this study suggest that the best maturity stage for harvesting iceberg lettuce for cold storage is 58 DAP due to this is stage maintains the overall visual quality during storage.

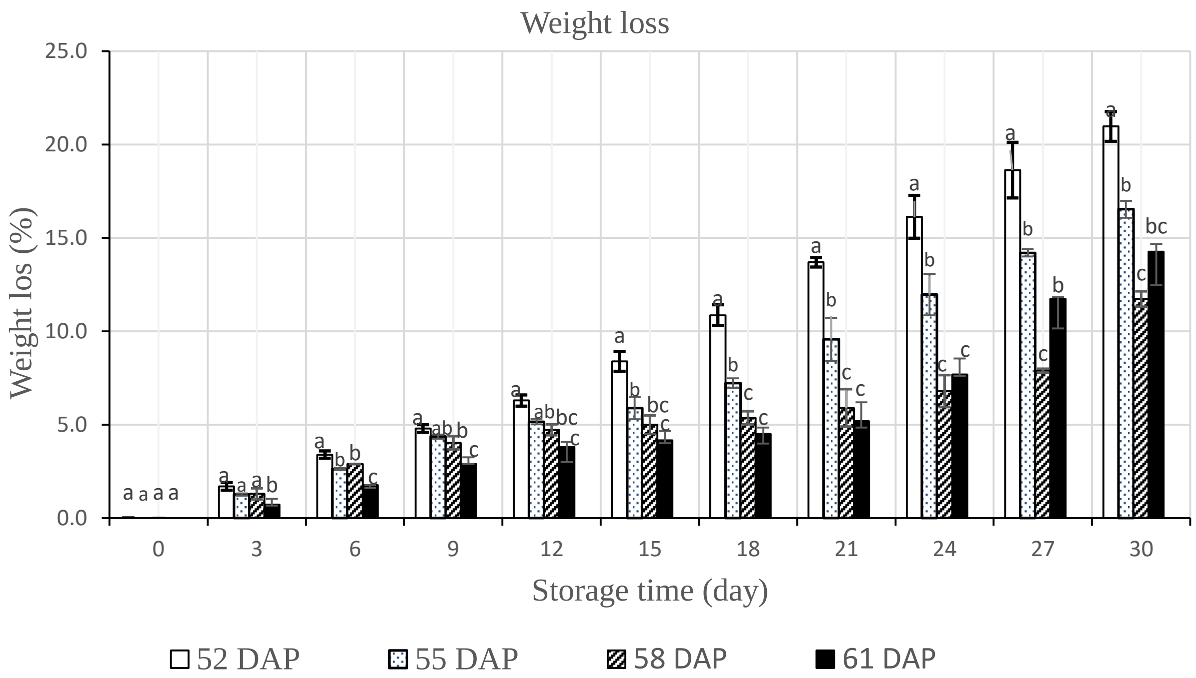
Weight loss

Figure 2 shows the effect of the maturity stages on the weight loss of iceberg lettuce during cold storage. Over the entire storage period, weight loss increased as the moisture content decreased, resulting in reductions in overall weight.

According to Shehata *et al.* (2012),the weight loss increases with the increase in the storage period due to the loss of moisture and dry matter through respiration and transpiration processes. Iceberg lettuce, with its high surface-to-volume ratio, is particularly susceptible to moisture loss, which can lead to wilting and shrinkage as result less appealing to consumers.

During early storage times, the percentage of weight loss was low due to packaging interactions with lower temperature-maintained transpiration process. As Yang *et al*. (2018) emphasized , maintaining low storage temperatures is essential for Chinese cabbage. This strategy effectively reduces the respiration rate of the vegetables and minimizes the loss of moisture and nutrients.

Throughout the storage period, the highest weight loss was recorded in the 52 DAP treatment. This high weight loss could have been derived from several factors, including its lower head compactness, a higher rate of transpiration, and increased skin permeability to water vapor. In contrast, the lowest weight loss was observed for the samples at 61 DAP (P <0.05). However,



Note: Vertical bars represent the standard error of the mean of three replications; bars having different letters are significantly different (P <0.05) according to Tukey's multiple comparison test.

Figure 2. Effect of maturity stage of iceberg lettuce on weight loss during cold storage

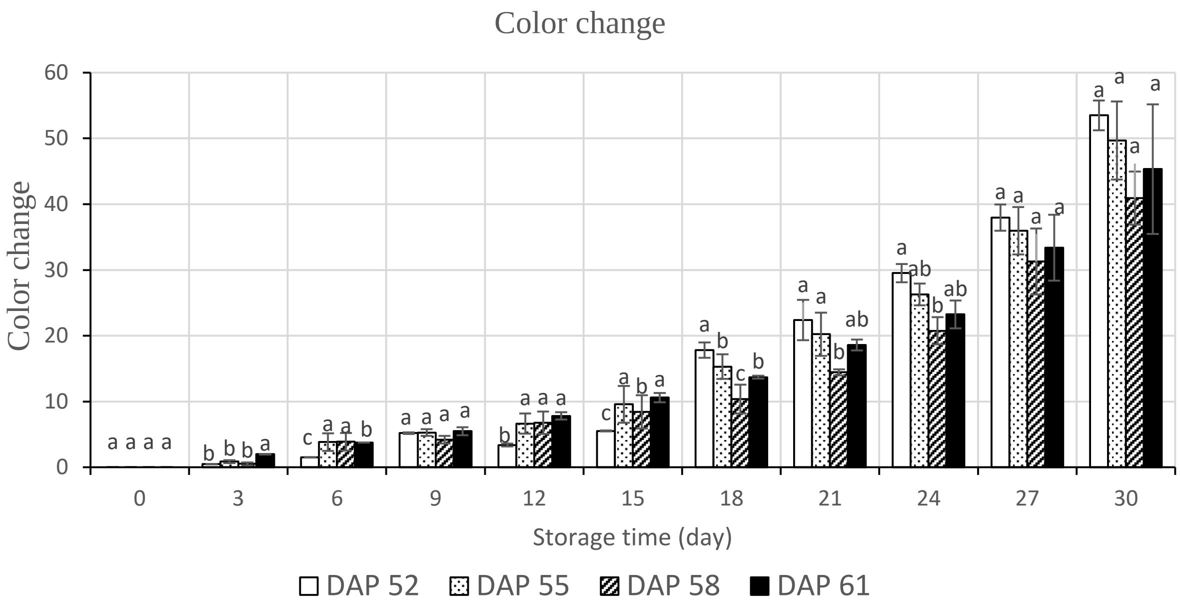
after a three-week storage period, the 58 DAP lettuces exhibited significantly lower weight loss (*P* <0.05). This could be attributed to their reduced metabolism, resistance to water loss, and lower respiration rates. Famuyini *et al*. (2020) reported that the highest values of weight loss for fruits over maturity might be due to the rate of respiration and concentration of CO_2 being higher inside the storage system causing toxicity to samples and resulting in unusable samples. The stomata of the 52 DAP sample was very active and had a high surface area to volume ratio, resulting high water loss and contributing to weight loss. This work also agrees with the work of Champa *et al.* (2007).

The 61 DAP lettuces exhibited significant water loss, likely attributable to the presence of cracks and blemishes, which rendered the heads more susceptible to increased water loss. Water loss is a primary factor in the deterioration of vegetables, as it directly reduces the fresh weight and quality, concurrently hastening the processes of ripening and senescence, thereby shortening their shelf-life. Balaguera-López *et al*. (2016) further observed that immature vegetables and fruits undergo more pronounced weight loss due to the incomplete development of cuticular waxes on the tissue surface, resulting in enhanced water loss through transpiration.

Color change

According to Xing *et al*. (2022), color serves as one of the crucial quality indicators for assessing the freshness of vegetables particularly for marketing. The effect of maturity stages on color changes (ΔE*) of iceberg lettuce during cold storage are presented in **Figure 3**. The results of **Figure 3** shows that the color change of iceberg lettuce was significantly (*P* <0.05) affected by the maturity stage. A gradual increase in color change was observed in all the maturity stages. Previous studies by Lee & Chandra (2018) corroborate these findings and attribute the increase in color change during lettuce storage at 10°C to biochemical and enzymatic ctivities, such as the formation of browning due to polyphenol oxidases.

Martín-Diana *et al*. (2008) also noted that prolonged storage periods led to a decrease in the value of fresh-cut lettuce. The heightened color



Note: Vertical bars represent the standard error of the mean of three replications; bars having different letters are significantly different (P <0.05) according to Tukey's multiple comparison test.

Figure 3. Effect of maturity stage on the color change of iceberg lettuce during cold storage

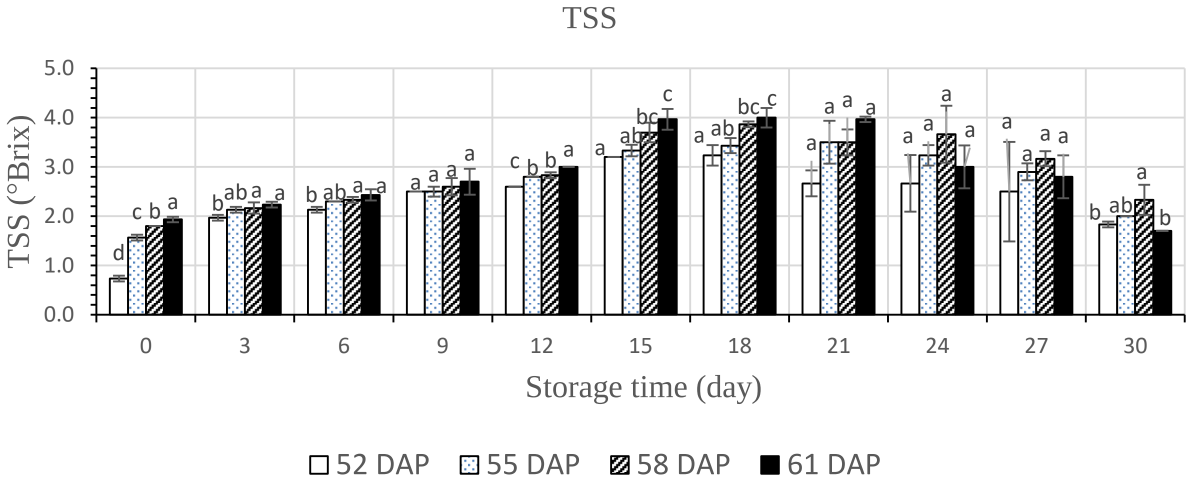
changes could likely be attributed to enzymes like chlorophyllase and magnesium decalactase, which reduce the levels of chlorophyll. The reduction in water content in vegetables also results in increased chlorophyllase activity and a subsequent decrease in chlorophyll levels, leading to increased color changes. This observation aligns with the findings of Aguero *et al*. (2008).

The results implied that up to the 15th day of storage, color change was lowest in the 52 DAP lettuce and was significantly affected on the 6th, 12th, and 15th days (P <0.05). However, after the 18th days of storage, the 52 DAP lettuce exhibited the highest color change (P <0.05) among the examined maturity stages, with no significant differences observed at 27 and 30 days *(P* >0.05). Among the four samples stored for one month, the 58 DAP samples displayed the lowest color change (ΔE^*) value after two weeks of storage, followed by the 61 DAP samples (**Figure 3**). The increase in color difference during storage indicated a degradation in the color quality of fresh iceberg lettuce.

These findings are consistent with the works of Hunter *et al*. (2017) who found that immature stages of lettuce have a shorter shelf-life and greater discoloration compared to mature heads of lettuce. However, in contrast, the research of Hilton *et al.* (2009) showed that pinking was more prevalent in over-mature lettuce compared to the tissues of young or mature vegetables, and Kang *et al*. (2008) also reported that over-mature lettuce heads exhibited higher levels of discoloration than mature heads.

Total soluble solids (TSS)

Figure 4 shows the effect of the maturity stages on the TSS of iceberg lettuce during the cold storage period. Total soluble solids increased gradually with the extended storage period, reaching a peak on the 18th day of storage, and then subsequently declined. Significant differences among maturity stages were also observed (P <0.05). Gutierrez *et al*. (2008) observed similar increases in TSS for goldenberry fruits at various maturity stages during storage. The results indicated that TSS in iceberg lettuce was highest for the 61 DAP maturity stage up to the 18th day of storage, with significant differences (P <0.05) observed among the different maturity stages. Conversely, the lowest TSS contents were recorded for the 52 DAP maturity stage (P <0.05) throughout the



Note: Vertical bars represent the standard error of the mean of three replications; bars having different letters are significantly different (P <0.05) according to Tukey's multiple comparison test.

Figure 4. Effect of maturity stage of iceberg lettuce on TSS during cold storage

storage period. After three weeks of storage, the 58 DAP lettuces exhibited the highest TSS content (*P* >0.05), while the lowest was observed in the 61 DAP samples at the 30-day storage time point (*P* <0.05).

The increase in TSS could be attributed to the breakdown of starches and polysaccharides into soluble sugars, whereas the decline could be associated with senescence, starch depletion, and the exhaustion of organic acids. Kaewklin *et al*. (2018) attributed changes in TSS during the maturation process to the hydrolysis of starches to simple sugars.

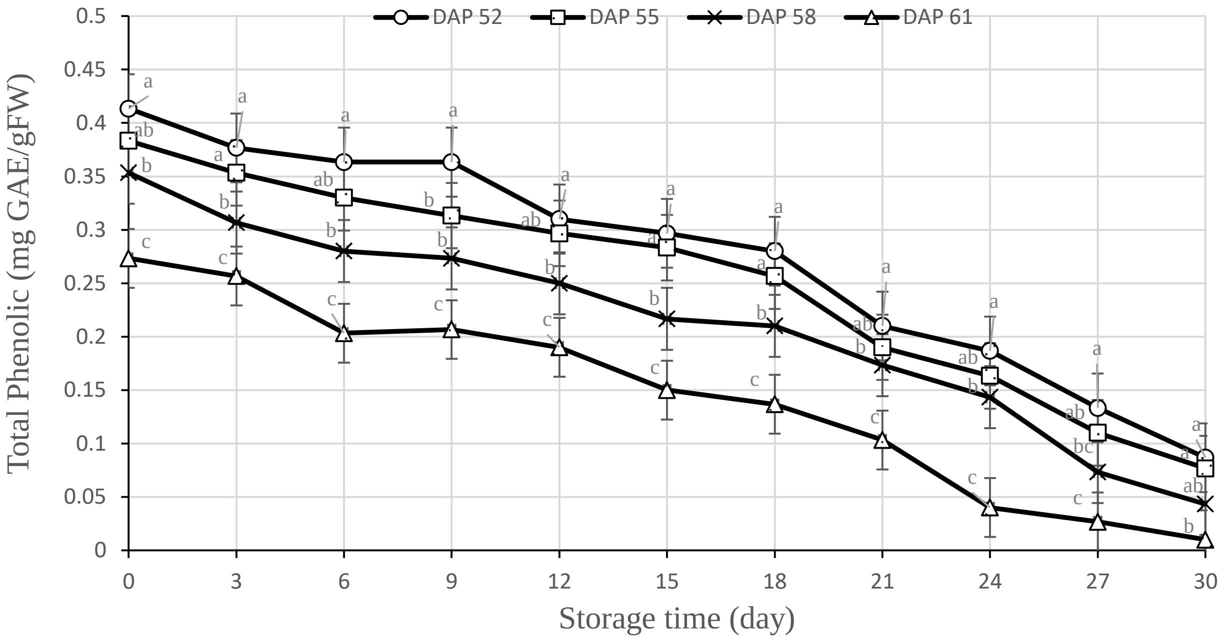
Variations in TSS values may arise from differences in chemical processes such as metabolism and respiration rates among maturity stages (Vargas *et al*., 2017). As noted by Balaguera-López *et al*. (2016), more mature vegetables tend to accumulate higher TSS. Gutierrez *et al*. (2008) observed similar patterns in cape gooseberry, where matured fruits displayed higher TSS levels than lower mature ones.

It is worth noting that when iceberg lettuce becomes over-mature, it can develop a bitter taste, leading to a loss of marketability. This underscores the importance of harvesting at the optimal maturity stage for ensuring good eating quality.

Phenolic compounds

Figure 5 shows a decreasing tendency of phenolic compounds with the increase of storage duration, with significant differences (*P* <0.05) among maturity stages. The decrease in phenolic content during storage may have been due to its reduced synthesis and transformation into other substances, as well as the breakdown of cellular compartmentalization with phenolics being oxidized by polyphenol oxidase and peroxidase enzymes to generate brown tannins (Liu *et al*., 2012; Patay *et al*., 2016). A slight decrease is supported by the work of Patil *et al*. (2017) who found phenolic content decreases during the cold storage of lettuce. In the paper of Hunter *et al*. (2017), levels of phenolic compounds associated with polyphenol oxidase discoloration were shown to be similar in immature, mature, and over-mature lettuce. Islam *et al*. (2019) also found that the phenolic concentration decreased during storage of romaine lettuce in modified atmosphere packaging at 8°C.

However, the results showed that small differences in the content of phenolic compounds were found among the maturity stages. Wurr *et al*. (2003) also found similar results in phenolics among mature, immature, and over-mature lettuce heads. According to **Figure 5**, the highest phenolics (0.39 mg GAE/g FW) were recorded at the 52 DAP stage of maturity at day zero, and the



Note: Vertical bars represent the standard error of the mean of three replications; bars having different letters are significantly different (P <0.05) according to Tukey's multiple comparison test.

Figure 5. Effect of maturity stage on the phenolic content of iceberg lettuce during cold storage

lowest (0.037 mg GAE/g FW) in the 61 DAP treatment at 30 days of storage (*P* <0.05). However, at 30 days of storage, the phenolic contents were not significantly different (*P* <0.05) among the first three stages of maturity (52, 55, and 58 DAP).

Our results agree with the previous work of Chutichudet *et al*. (2011) who found significant changes in total phenolic content in lettuce at different plant ages, with the highest phenolics at the early stages of development due tomature plants were under oxidative stress as the plant became senescent. Generally, our results imply that total phenolic content tends to decline during the maturity progress of iceberg lettuce and agrees with the results of Zhang *et al.* (2022) on plums, and Wojdyło *et al.* (2020) on apples.

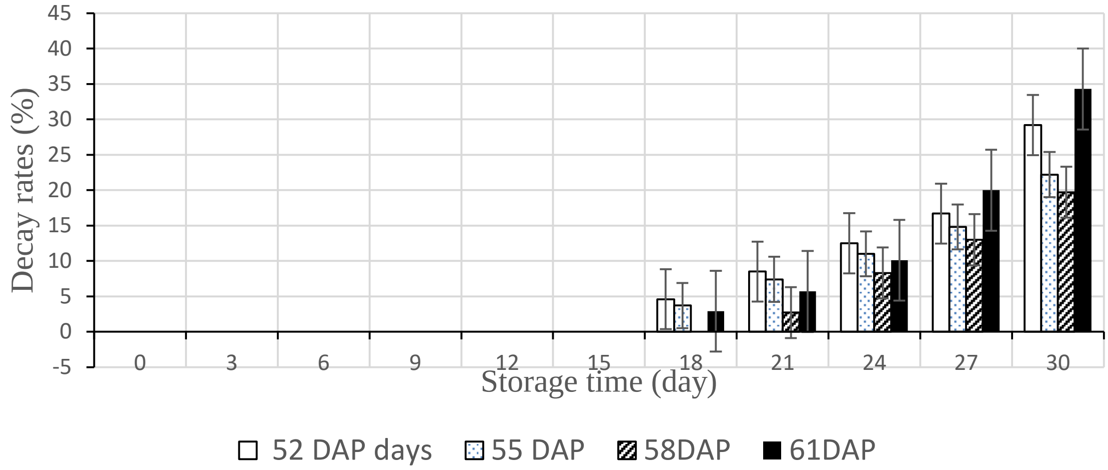
Decay Rate

In our results shown in **Figure 6**, no decay symptoms were found for the first two weeks of storage. However, lettuce decay became apparent in all maturity stages after 18 days due to appearance of symptoms of discoloration, softening, water-logging, and tissue breakdown with the least severe decay observed at stage 3 (58 DAP). The increase in decay seemed to begin from wounded tissue surfaces when accumulated free water from condensation at the bottom of the LDPE film directly contacted the lettuce tissue, leading to decay due to the rapid multiplication of microorganisms. It also might have been due to tissue breakdown as result of the removal of moisture from samples.

As shown in **Figure 6,** the decay rate was highest in 52 DAP lettuce until 24 days of storage, followed by 61 DAP, and lowest in 58 DAP. This is likely because the 52 DAP lettuces had more stomata than the others, a higher metabolic rate, and a more vulnerable skin structure for water loss and decay. This idea is further supported by the work of Kang *et al.* (2008).

According to Champa *et al.* (2007), cabbages harvested at early mature stages are in an actively growing phase with rapid cell division and enlargement. The 52 DAP icebergs had a thin cuticle and epidermal layer, which made them susceptible to damage and disruption of the cuticle, allowing for increased water loss.

However, our results also show that during the evaluation periods of 27 and 30 days, the



Note: Vertical bars represent the standard error of the mean of three replications.

Figure 6. Effect of maturity stage of iceberg lettuce on the decay rate after 30 days of storage

decay was higher in the 61 DAP lettuce due to its higher respiration rate and high susceptibility to splitting, physiological disorders, and pathogens (**Figure 6**). This work agrees with the results of Moneruzzaman *et al*. (2008). On the basis of our results, we can conclude that the decay rate was highest in the 61 DAP lettuce, followed by 52 DAP, and lowest in 58 DAP, with significant differences among the maturity stages. The texture of immature iceberg lettuce heads is soft and easily damaged while lettuce heads with optimum maturity have firm heads and maximal storage life (Martínez-Sánchez *et al.*, 2012). This is because multi-leaf lettuce, which is an advanced maturity stage, has higher firmness and longer shelf life than baby-leaf lettuce, which is a less mature stage. Martínez-Sánchez *et al*. (2008) reported that the rate of deterioration is related to metabolic processes and the respiration rate, which are usually higher in younger leaves.

Conclusions

In this research experiment, the maturity stage at harvest was identified as a critical factor in ensuring the quality of iceberg lettuce, particularly in the situation of exportation. The most suitable maturity stage was found to be 58 DAP for optimal long-term storage with minimal quality deterioration. This stage exhibited the lowest weight loss, minimal color change, the lowest decay rate, and the highest overall visual quality. In conclusion, it is recommended that iceberg lettuce be harvested at 58 DAP for long-distance exportation, which holds benefits for consumers, growers, and traders alike. Furthermore, this study provides invaluable insights into the maintenance of overall vegetable quality and the reduction of post-harvest losses, all within the framework of days after planting. Further study is required to examine many lettuce varieties by using different storage temperatures and relative humidities.

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References

Aguero M. V., Barg M. V., Yommi A., Camelo A. & Roura S. I. (2008). Postharvest changes in water status and chlorophyll content of lettuce (*Lactuca sativa* L.) and their relationship with overall visual quality. Journal of Food Science. 73(1): S47-S55. DOI: 10.1111/j.1750-3841.2007.00604.

Aguero M. V., Ponce A. G., Moreira M. R. & Roura S. I. (2011). Lettuce quality loss under conditions that favor the wilting phenomenon. Postharvest Biology and Technology. 59(2): 124-131. DOI: 10.1016/j.postharvbio.2010.08.018.

Balaguera-López H. E., Martínez-Cárdenas C. A. & Herrera-Arévalo A. (2016). Effect of the maturity stage on the postharvest behavior of cape gooseberry (*Physalis peruviana* L.) fruits stored at room temperature. Bioagro. 28(2): 117-124.

Belisle C. E., Sargent S. A., Brecht J. K., Sandoya G. V. & Sims C. A. (2021). Accelerated shelf-life testing to predict quality loss in romaine-type lettuce. HortTechnology. 31(4): 490-499.

Binh L. N., Duy L. N. D., Dung N. T. P., Lien D. T. P., Minh N. N. & Phuong D. D. C. (2014). Overview and situation of vegetable production in Vietnam-case study of sweet potato and purple onion. Market Access through Competency Based Education and Training in Horticulture (MACBETH). Retrieved from https://standardsfacility.org/sites/default/files/STDF_PG_326_ValueChainAnalysisVietNam_Feb-14.pdf on May 3, 2023.

Champa W.A. H., Palipane K. B., Weerakkody W. A. P. & Fernando M. D. (2007). Maturity indices for harvesting of cabbage (*Brassica oleracear* L.) variety green coronet. Tropical Agricultural Research. 19: 254-264.

Chutichudet B., Chutichudet P. & Kaewsit S. (2011). Influence of developmental stage on activities of Polyphenol Oxidase, internal characteristics and colour of lettuce cv. Grand Rapids. American Journal of Food Technology. 6(3): 215-225.

Eriksson. M., Strid I. & Hansson P. A. (2012). Food losses in six Swedish retail stores: wastage of fruit and vegetables in relation to quantities delivered. Journal of Resources, Conservation and Recycling. 68: 14-20. DOI: 10.1016/j.resconrec.2012.08.001.

Famuyini J., Patrick O. A. & Sedara A. (2020). Effect of maturity stage on quality and shelf life of tomato (*Lycopersicon esculentum* Mill) using refrigerator storage system. Eurasian Journal of Agricultural Research. 4(1): 23-44.

Faqeerzada M. A., Rahman A., Joshi R., Park E. & Cho B. K. (2018). Postharvest technologies for fruits and vegetables in South Asian countries. Korean Journal of Agricultural Science. 45(3): 325-353.

Farahanian Z., Zamindar N., Goksen G., Tucker N., Paidari S. & Khosravi E. (2023). Effects of nano-bentonite polypropylene nanocomposite films and modified atmosphere packaging on the shelf life of fresh-cut iceberg lettuce. Coatings. 13(2): 349. DOI:10.3390/coatings13020349.

Gil M. I., Tudela J. A., Martínez-Sánchez A. & Luna M. C. (2012). Harvest maturity indicators of leafy vegetables. Stewart Postharvest Review. 8(1): 1-9.

Gutierrez M. S., Trinchero G. D., Cerri A. M., Vilella F. & Sozzi G. O. (2008). Different responses of goldenberry fruit treated at four maturity stages with the ethylene antagonist 1-methylcyclopropene. Postharvest Biology and Technology. 48(2): 199-205. DOI: 10.1016/j.postharvbio.2007.10.003.

Hilton H. W., Clifford S. C., Wurr D. C. E. & Burton K. S. (2009). The influence of agronomic factors on the visual quality of field-grown, minimally-processed lettuce. Journal of Horticultural Science and Biotechnology. 84(2): 193-198.

Hunter P. J., Atkinson L. D., Vickers L., Lignou S., Oruna-Concha M. J., Pink D., Hand P., Barker G., Wagstaff C. & Monaghan J. M. (2017). Oxidative discolouration in whole-head and cut lettuce: biochemical and environmental influences on a complex phenotype and potential breeding strategies to improve shelf-life. Euphytica. 213(180): 1-16. DOI: 10.1007/s10681-017-1964-7.

Ikegaya, A., Toyoizumi T., Ohba S., Nakajima T., Nagafuji A., Nakamura S., Seiko Ito & Arai E. (2019). Quality evaluation of fruits and vegetables in mixed cargo exported by sea. The Horticulture Journal. 88(4): 548-558. DOI: 10.2503/hortj.UTD-077.

Islam M. Z., Lee Y. T., Mele M. A., Choi I. L., Jang D. C., Ko Y. W., Kim Y. D. & Kang H. M. (2019). Effect of modified atmosphere packaging on quality and shelf life of baby leaf lettuce. Quality Assurance and Safety of Crops and Foods. 11(8): 749-756. DOI: 10.3920/QAS2019.1626.

Kaewklin P., Siripatrawan U., Suwanagul A. & Lee Y. S. (2018). Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit. International Journal of Biological Macromolecules. 112: 523-529. DOI: 10.1016/j.ijbiomac.2018.01.124.

Kang Y., Choi J., Jeong M. & Kim D. (2008). Effect of maturity at harvest on the quality of head lettuce during storage. Korean Journal of Horticultural Science and Technology. 26(3): 272-276.

Kim M. J., Moon Y., Kopsell D. A., Park S., Tou J. C. & Waterland N. L. (2016). Nutritional value of crisphead ‘Iceberg’ and romaine lettuces (*Lactuca sativa* L.). Journal of Agricultural Science. 8(1): 37-45. DOI: 10.5539/jas.v8n11pxx.

Lee J. S. & Chandra D. (2018). Effects of different packaging materials and methods on the physical, biochemical and sensory qualities of lettuce. Journal of Food Science and Technology. 55(5): 1685-1694. DOI: 10.1007/s13197-018-3081-6.

Liu H., Zhao H., Ye L., Fan D. & Wang. Z. (2022). Effects of the combination of phytic acid and vacuum packaging on storage quality of fresh-cut lettuce. Food Science and Technology Research. 28(1): 45-52.

Martín-Diana A. B., Rico D. & Barry-Ryan C. (2008). Green tea extract as a natural antioxidant to extend the shelf-life of fresh-cut lettuce. Innovative Food Science and Emerging Technologies. 9(4): 593-603. DOI: 10.1016/j.ifset.2008.04.001.

Martínez-Sánchez A., Allende A., Cortes-Galera Y. & Gil M. I. (2008). Respiration rate response of four baby leaf Brassica species to cutting at harvest and fresh-cut washing. Postharvest Biology and Technology. 47(3): 382-388. DOI: 10.1016/j.postharvbio.2007.07.010.

Martínez-Sánchez A., Luna M. C., Selma M. V., Tudela J. A., Abad J. & Gil M. I. (2012). Baby-leaf and multi-leaf of green and red lettuces are suitable raw materials for the fresh-cut industry. Postharvest Biology and Technology. 63(1):1-10. DOI: 10.1016/j.postharvbio.2011.07.010.

Meena S. S. & Kulakarni A. (2022). Management of Iceberg lettuce quality. Asian Journal of Agricultural Extension, Economics and Sociology. 40(10): 593-602. DOI: 10.9734/ajaees/2022/v40i1031119.

Moneruzzaman K. M., Hossain A. B. M. S., Sani W. & Saifuddin M. (2008). Effect of stages of maturity and ripening conditions on the biochemical characteristics of tomato. American Journal of Biochemistry and Biotechnology. 4(4): 336-344.

Patay E. B., Sali N., Kőszegi T., Csepregi R., Balázs V. L., Németh T. S. & Papp. N. (2016). Antioxidant potential, tannin and polyphenol contents of seed and pericarp of three Coffea species. Asian Pacific Journal of Tropical Medicine. 9(4): 366-371.

Patil S. S., Dhumal S. S., Patgaonkar D. R., Garande V. K. & Kaur M. (2017). Post-harvest behavior of different lettuce cultivars and their cut form under different storage conditions. International Journal of Environment, Agriculture and Biotechnology. 2(3): 1232-1246. DOI: 10.22161/ijeab/2.3.29.

Quamruzzaman A. K. M., Islam F., Akter L. & Mallick S. R. (2022). Effect of maturity indices on growth and quality of high value vegetables. American Journal of Plant Sciences. 13(7): 1042-1062.

Rizzolo A. & Zerbini P. E. (2012). Harvest maturity indicators - Introduction. Stewart Postharvest Review. 8(1): 1-3. DOI: 10.2212/spr.2012.1.1.

Shehata S. A., El-Sheikh T. M., Mohamed M. E. & Saleh M. A. (2012). Effect of some pre-and postharvest treatments on browning inhibition in fresh cut lettuce during cold storage. Journal of Applied Sciences. 8(1): 25-33.

Singh R., Giri S. K. & Kotwaliwale N. (2014). Shelf-life enhancement of green bell pepper (*Capsicum annuum* L.) under active modified atmosphere storage. Food Packaging and Shelf Life. 1(2): 101-112. DOI: 10.1016/j.fpsl.2014.03.001.

Singleton V.L., Orthofer R. & Lamuela-Raventós R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In Methods in enzymology. 299: 152-178. DOI: 10.1016/s0076-6879(99) 99017-1.

Tilahun S., Park S., Solomon T., Choi H. R. & Jeong C. S. (2019). Maturity stages affect nutritional quality and storability of tomato cultivars. CyTA-Journal of Food. 17(1): 87-95.

Vargas-Arcila M., Cartagena-Valenzuela J. R., Franco G., Correa-Londoño G. A., Quintero-Vásquez L. M. & Gaviria-Montoya C. A. (2017). Changes in the physico-chemical properties of four lettuce (*Lactuca sativa* L.) varieties during storage. Ciencia Tecnología Agropecuaria. 18(2): 257-273. DOI: 10.21930/rcta.vol18_num2_art:632.

Vitti M. C. D., Yamamoto L. K., Sasaki F. F., Aguila J. S. D., Kluge R. A. & Jacomino A. P. (2005). Quality of minimally processed beet roots stored in different temperatures. Brazilian Archives of Biology and Technology. 48(4): 503-510. DOI: 10.1016/j.lwt.2021.112877.

Wojdyło A. & Oszmiański J. (2020). Antioxidant activity modulated by polyphenol contents in apple and leaves during fruit development and ripening. Antioxidants. 9(7): 567. DOI: 10.3390/antiox9070567.

Wurr D., Parr A., Feuerhelm S., Kennedy S., Pennings H., Oost E., Cornai I., Harriman M., Sawday J. & Tucker A. (2003). Improving the quality and shelf-life of cut salad products. DEFRA final report for project number HLO142 (CSA 4969, HORT 232).

Xing Y., Liao X., Wu H., Qiu J., Wan R., Wang X., Rumeng Yi., Qinglian Xu & Liu X. (2022). Comparison of different varieties on quality characteristics and microbial activity of fresh-cut pineapple during storage. Foods. 11(18): 2788. DOI: 10.3390/ foods11182788.

Yang D., Li D., Xu W., Liao R., Shi J., Fu Y., Wang J., Wang Y.& He X. (2018). Design and application of a passive modified atmosphere packaging for maintaining the freshness of Chinese cabbage. Lwt. 94: 136-141. DOI: 10.1016/j.lwt.2018.04.036.

Zhang H., Pu J., Tang Y., Wang M., Tian K., Wang Y. & Deng Q. (2022). Changes in phenolic compounds and antioxidant activity during development of 'Qiangcuili'and 'Cuihongli'fruit. Foods. 11(20): 3198. DOI: 10.3390/foods11203198.