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Full Paper

Effect of Storage Conditions on Postharvest Quality of Water Spinach (*Ipomoea aquatica* Forsk)

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Abstract

Water spinach (*Ipomoea aquatica* Forsk.) is a widely consumed leafy vegetable, and its postharvest quality is highly affected by storage conditions. This study aimed to evaluate the effects of different storage conditions on the quality of harvested water spinach. Harvested water spinach leaves were stored in a controlled-environment chamber at 15 °C and 60% relative humidity (Treatment 1) and 30 °C and 80% relative humidity (Treatment 2) for four days. Additionally, the water spinach leaves were stored under ambient conditions (27 ± 1.5 °C and 88 ± 1.4% relative humidity). Weight reduction, chlorophyll degradation, leaf color, visual quality, and wilting quality of the water spinach were recorded. The weight reduction of the leaves was 72.06%, 91.91%, and 90.58% for treatments 1, 2, and the ambient condition, respectively. The corresponding chlorophyll reduction percentages were 4.39, 7.56, and 5.39%, respectively. The corresponding color-difference (ΔE) values were 3.596±1.65, 5.805±1.71, and 17.15±1.07. According to the results, treatment 1 showed significantly lower ($p<0.05$) weight reduction than the other methods and a significant ($p<0.05$) delay in chlorophyll degradation in leaves, which affected ΔE values. In conclusion, treatment 1 slows senescence in water spinach. Therefore, low temperatures with moderate relative humidity levels maintain the freshness and marketability of water spinach, thereby improving postharvest management.

Keywords: chlorophyll, controlled environment, leafy vegetables, postharvest, psychrometrics

Introduction

Postharvest losses refer to the decline in the quantity and quality of food products from harvest to consumption [1]. The production of fresh vegetables is complex due to their high perishability and bulkiness, which make them more challenging to manage during the postharvest period [2]. The Food and Agriculture Organization (2019) reported that more than 15% of the food produced globally, including vegetables, is lost during the postharvest stage before it reaches the retail stage of the food supply chain [3]. The physiological nature of fruits and vegetables makes them highly prone to deterioration during transit and storage, particularly under high temperatures and humidity, resulting in significant crop losses [4].

Significant postharvest losses in leafy vegetables, often exceeding 50%, are attributed to various biological and environmental factors. The decline in quality and deterioration of harvested leafy greens is evident in yellowing from chlorophyll loss, wilting, textural degradation, and decay from pathogenic breakdown, among other issues. Water loss due to transpiration is a key physiological process that contributes to their deterioration. This process leads to a loss of freshness, reflected in wilting, shriveling, and a reduction in firmness, crispness, and succulence, all essential aspects of freshness. If leafy vegetables lose more than 3% of their original fresh weight, they become unsellable [5]. These physiological changes emphasize the need for appropriate storage conditions to minimize postharvest losses in leafy vegetables.

Maintaining optimal temperature and relative humidity during postharvest storage is essential to reduce deterioration in leafy vegetables. Psychrometric processes play a crucial role in agriculture and food processing by supporting storage and preservation, drying and dehydration, quality control, cold chain management, process optimization, food safety, and the retention of sensory properties. Through efficient temperature and humidity control, these processes help maintain product quality, extend shelf life, and improve the safety of agricultural and food products [6]. Psychrometrics focuses on the thermodynamic properties of moist air and applies these properties to evaluate conditions and processes involving moist air. The most used psychrometric variables include temperature, relative humidity, dew point temperature, and wet bulb temperature.

Most fruits and vegetables undergo rapid aging and quality deterioration after harvest, including increased respiration, softening, tissue breakdown, lipid peroxidation, water loss, and declines in visual appearance, flavor, texture, aroma, and nutritional value. Consequently, the primary goal of postharvest storage for horticultural crops is to delay senescence and preserve these essential qualities during storage [7]. One of the significant postharvest problems with green vegetables is the yellowing of tissues due to senescence, an undesirable physiological process that accelerates fresh produce deterioration and reduces both nutritional and commercial value [7, 8]. Chlorophyll degradation is the leading indicator of senescence in green vegetables [9], exhibited by a loss of green color and shortening shelf life [10].

Among green leafy vegetables, water spinach (*Ipomoea aquatica* Forsk.) is a fast-growing aquatic plant widely cultivated in Southeast Asia, India, and southern China [11]. Water spinach production, with a planting area of over 167 ha, is in Bobai County, Guangxi province [12]. The optimal growth conditions of the water spinach are temperatures between 20-27 °C and relative humidity above 75% to support healthy development [13]. Under optimal growing conditions, the water spinach can produce annual yields of approximately 90 tons of fresh weight per hectare [14]. Commercial cultivation of water spinach is carried out across tropical and subtropical regions to meet the nutritional requirements of the growing human population, given its high nutritional and medicinal value [15].

Water spinach is an excellent source of minerals and vitamins and is considered among the richest sources of carotenoids and chlorophylls [16, 17]. Traditional medicine has also used water spinach to treat swelling, food poisoning, and antioxidant-related disorders [18]. It is also recommended for the treatment of liver-related disorders and intestinal problems. The plant also inhibits prostaglandin generation [19]. In the ancient practices of Indian medicine (Ayurveda) and homeopathy, water spinach leaf extracts are administered orally to help alleviate disorders associated with oxidative stress, owing to their antioxidant properties [16].

Leafy vegetables are highly susceptible to postharvest deterioration due to their high water content, leading to rapid loss of green color after harvest. As a result, their postharvest storage life is relatively short [20]. Water spinach requires specialized processing treatments, such as drying, to reduce postharvest losses [21, 22]. According to Thokchom *et al.*, (2024), water spinach is arranged in 15 cm layers within bamboo crates and stored with crushed ice for long-distance transportation and storage [23]. However, no studies are available on evaluating the preservation temperature and relative humidity of harvested water spinach. Therefore, this study aims to assess the effects of different storage conditions on the quality of harvested water spinach.

Materials and Methods

Materials

Fresh water spinach leaves at the commercial maturity stage were used in the study. The harvested water spinach leaves were sorted and cleaned using tap water. The damaged, discolored, decayed, and wilted leaves were discarded during the sorting. The washed leaves were wiped with clean tissue paper to remove water molecules from their surfaces. The dimensions of the leaves, including their length and width, were measured using a Venier caliper (CD-30AX, Japan). The leaves were spread as a thin layer on the tray in the chamber (ICHeco 110, Germany). The initial measurements were taken: weight, color, chlorophyll content, visual quality, and wilting scores. The specific experimental control conditions of temperature and relative humidity were obtained in the storage chamber. All the leaves were stored in a storage chamber under different environmental conditions for four days. The leaves were stored at 15 °C and 60% relative humidity (Treatment 1) and 30 °C and 80% relative humidity (Treatment 2) in the storage chamber. In addition, experiments were conducted under ambient conditions. Measurements for weight, color, chlorophyll content, visual quality, and wilting scores were recorded every 24 hours over a four-day storage period. Each experiment was replicated three times to ensure the reliability and accuracy of the results.

Preliminary Calculations

The experimental storage conditions for harvested water spinach, such as temperature and relative humidity, were identified through preliminary calculations. Thokchom *et al*., (2024) reported that water spinach is highly perishable and should be stored at 10-15 °C with high humidity. However, the very low temperature requires more energy, and the higher humidity can lead to fungal infections. Parker and Sutton (1993) also reported that high humidity can cause disease conditions if temperatures are favorable [24]. Therefore, psychrometric calculations were performed to determine optimal conditions for controlled environments by examining various combinations of temperature and relative humidity. Table 1 presents the results of psychrometric calculations for selected combinations of temperature (15 °C, 25 °C, and 30 °C) and relative humidity levels (40%, 60%, and 80%). To minimize energy consumption, temperatures were set close to ambient, as significant deviations from it can increase energy use in the storage chamber. The humidity ratios (kg of water vapor per kg of dry air) were calculated for each temperature-relative humidity combination. These calculations provided a critical understanding of the moisture content of air under different conditions. Table 1 shows that, at a given temperature, the humidity ratio increases with higher relative humidity. For instance, at 15 °C, the humidity ratio is 0.0085, 0.0063, and 0.0042 kg/kg dry air at relative humidity levels of 80%, 60%, and 40%, respectively. Similarly, as temperature increases, the humidity ratio increases for the same relative humidity levels, as observed at 25 °C and 30 °C. Based on the data, the conditions of 15 °C and 60% relative humidity, and 30 °C and 80% relative humidity were selected for the experiment. Further, 15 °C and 30 °C were within the range of ambient air temperatures.

The humidity ratio is the ratio of the weight of water vapor to the weight of dry air in a moist air sample, typically expressed in kg water per kg dry air. The humidity ratio of the storage conditions was calculated using Equation 1. Where W_s denotes the humidity ratio (kg of water/ kg of dry air), p_{ws} denotes the saturation vapor pressure (Pa), p denotes the atmospheric pressure (Pa), and t is the temperature.

$$W_s = 0.62198 \frac{p_{ws}}{p - p_{ws}} \quad \text{Equation 1}$$

$$T = t + 273.15 \quad \text{Equation 2}$$

$$ln\, p_{ws} = \frac{C_1}{T} + C_2 + C_3T + C_4T^2 + C_5T^3 + C_6T^4 + C_7 lnT \quad \text{Equation 3}$$

Where,
C_1=-5.674 535 E+03, C_2=6.392 524 7 E+00, C_3=-9.677 843 E-03, C_4=6.221 570 1 E-07, C_5=2.074 782 5 E-09, C_6=-9.484 024 0 E-13, C_7=4.163 501 9 E+00

Table 1. Preliminary psychrometric calculations for the storage conditions of water spinach

Temperature (°C)	Relative humidity (%)	Humidity Ratio (kg/kg dry air)
15	80	0.0085
	60	0.0063
	40	0.0042 [a]
25	80	0.0160 [b]
	60	0.0119 [c]
	40	0.0079 [a]
30	80	0.0216
	60	0.0161 [b]
	40	0.0106 [c]

English small letters (a, b, and c) express similar humidity levels at different temperatures and relative humidity.

Determination of the weight reduction of water spinach leaves

Initially, 50 g of leaves were measured and placed in a thin layer on the tray. The weight of the tray was measured and recorded separately. The total weight of the samples was measured every 24 hours during the four-day storage period using an electric balance (KERN-EMB 1000-2, Germany) for both treatment 1 and treatment 2. Based on the initial and final leaf weights, the weight reduction was calculated using Equation 4.

$$Weight\ reduction\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100\% \qquad \text{Equation 4}$$

Determination of the chlorophyll changes of the water spinach leaves

The chlorophyll content of the leaves was measured at three to four locations on the leaf surface using a SPAD meter (SPAD-502 Plus, Japan). The SPAD meter measures the relative amount of chlorophyll in a leaf by measuring it at two wavelengths. Based on this characteristic of chlorophyll, the SPAD meter measures the absorbance of the leaf in the red and near-infrared regions. Using these two absorbances, the meter calculates a numerical SPAD value proportional to chlorophyll in the leaf. First, the SPAD meter was calibrated. Then, the leaf sample was inserted into the slot of the measuring head. The receiving window completely covered the sample. The measuring head was pressed until a beep sound, and the measured value appeared on the display. The readings were taken every 24 hours during the four-day storage period from randomly selected leaves. The average chlorophyll content was calculated using Equation 5.

$$Chlorophyll\ changes\ (\%) = \frac{Initial\ chlorophyll - Final\ chlorophyll}{Final\ chlorophyll} \times 100\% \qquad \text{Equation 5}$$

Determination of the color composition of the leaves

Water spinach leaf color was measured using three methods: instrumental measurement with a colorimeter, comparative assessment using a standard color chart, and subjective visual scoring based on consumer preferences for leafy vegetable color.

Colorimeter method

The color of the samples was determined using a calibrated colorimeter (CR-10 Plus, Japan) at 24-hour intervals throughout the storage period. Three leaves were randomly selected from the water spinach sample. The selected leaves were placed on a white background. The colorimeter was placed on the leaf surface, and the color values (L^*, a^*, b^*) were recorded. For each measurement, three values were taken, and average color values were calculated based on the L^* (lightness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness) color values. According to the color values, the color difference of the leaves (ΔE) was calculated using Equation 6.

$$Color\ difference\ (\Delta E) = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{Equation 6}$$

Further, the hue angle (h°) was calculated using Equation 7. The hue angle can be adjusted to a* and b*. No correction is needed for the first quadrant, a* > 0 and b* > 0, where the hue angle ranges from 0° to 90°. In the second quadrant, a* < 0 and b* > 0; for angles between 90° and 180°, 180° is added to the calculated hue angle.

Similarly, in the third quadrant, a* < 0 and b* < 0, where the angle ranges from 180° to 270°, 180° is also added. For the fourth quadrant, a* > 0 and b* < 0; the angle ranges from 270° to 360°; 360° is added if the result is negative. This adjustment ensures the hue angle remains within the correct range corresponding to its quadrant.

$$h^{\circ} = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{Equation 7}$$

Standard color chart method

Visual color was recorded using standard color charts (Sixth edition, 2015:2019 reprint) at 24-hour intervals throughout storage. Leaves were selected randomly from the sample and compared with the color chart. The names of the colors and relevant code numbers were recorded.

Visual method

Score values were used to visually determine the color changes of water spinach leaves. Table 2 describes the colors with their respective scores.

Table 2. The score values for the color changes of water spinach

Description of Colors	Scores
Dark green	1
Light green	2
Yellowish green	3
Greenish yellow	4
Yellow	5

Figure 2 shows color images of water spinach corresponding to the identified scores. The data were recorded every 24 hours during the storage period (4 days).

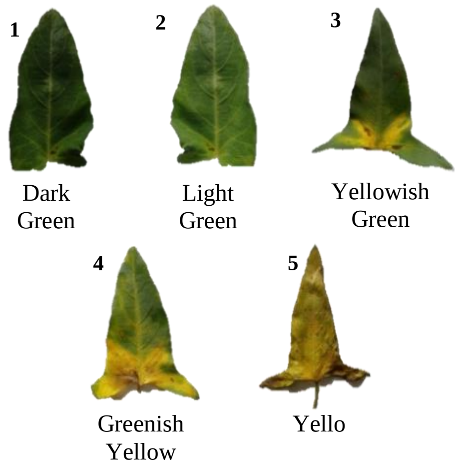

Figure 2. The color images of the water spinach leaves

Determination of visual quality and wilting of water spinach leaves

The visual quality and leaf wilting were determined using the relevant score values in Tables 3 and 4. The data were recorded every 24 hours for 4 days.

Table 3. A scale for evaluating the overall visual quality of products

Description	Rate	Score
No signs of degradation	Excellent	1
Minor signs of decline, although unsatisfactory	Good	2
There is a noticeable but not significant decline in the saleability limit.	Fair	3
Significant degradation and usability limit	Poor	4
Unusable	Extremely poor	5

Table 4. A scale for evaluating the wilting of green vegetables

Description of wilting	Score
No wilting	1
Slight wilting	2
Moderate condition	3
Severe condition	4
Extreme, unacceptable in everyday circumstances	5

Statistical Analysis

Graphs illustrating weight-reduction rate and percentage, chlorophyll change percentage, color score values, visual quality, and leaf wilting were generated in Microsoft Excel 2019. Results are presented as mean ± standard deviation.

Results and Discussion

The ambient temperature and relative humidity during the experiments were 27±1.5 °C and 88±1.4%, respectively.

The Weight of the Water Spinach Leaves

Figure 3 shows the weight-reduction rate of water spinach leaves under three treatments over four days. In all experiments, the steepest decline occurred on the first day, followed by gradual weight loss.

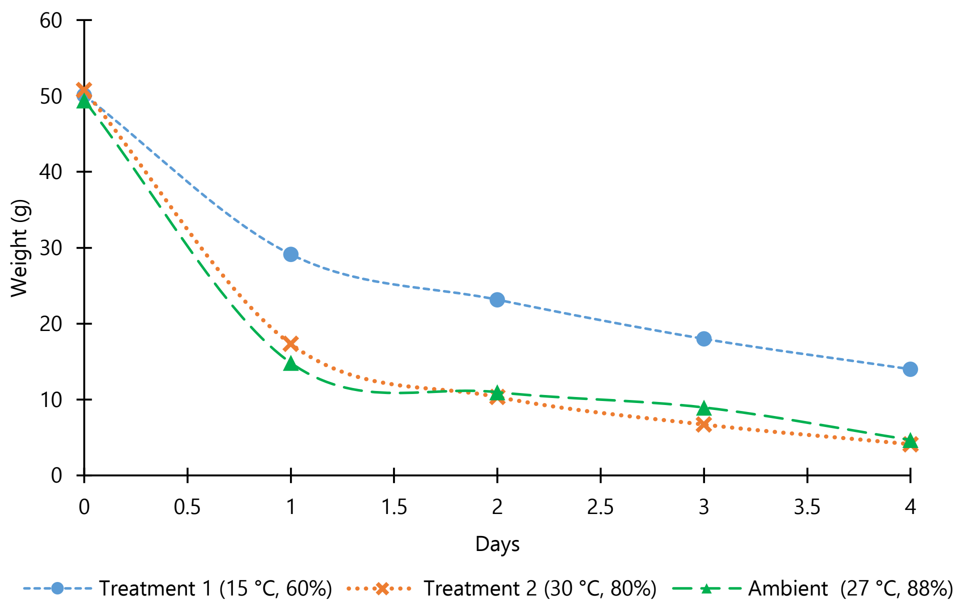

Figure 3. The weight reduction rate of the water spinach leaves

Treatment 1, maintained at 15 °C with 60% relative humidity, showed the slowest weight reduction. This can be attributed to the cooler temperature and lower humidity, which reduce the rate of water evaporation and transpiration, effectively slowing down weight loss. In contrast, Treatment 2, conducted at 30 °C with 80% RH, initially showed a faster weight reduction than Treatment 1 but slowed after the first day. The higher humidity ratio in treatment 2 accelerated water loss, while the relatively higher humidity moderated evaporation to some extent, preventing an even sharper decline. The experiment under ambient conditions and treatment 2 shows similar trends because their humidity ratios are identical. Therefore, treatments 2 and ambient show water loss through respiration and microbial activity, leading to more rapid degradation and weight loss than in treatment 1. Jany *et al.*, (2010) also reported that the rate of weight loss increased with storage time for leafy vegetables such as cabbage and cauliflower [25].

Figure 4 shows the final weight reduction of the water spinach leaves as a percentage under different conditions, revealing significant variations.

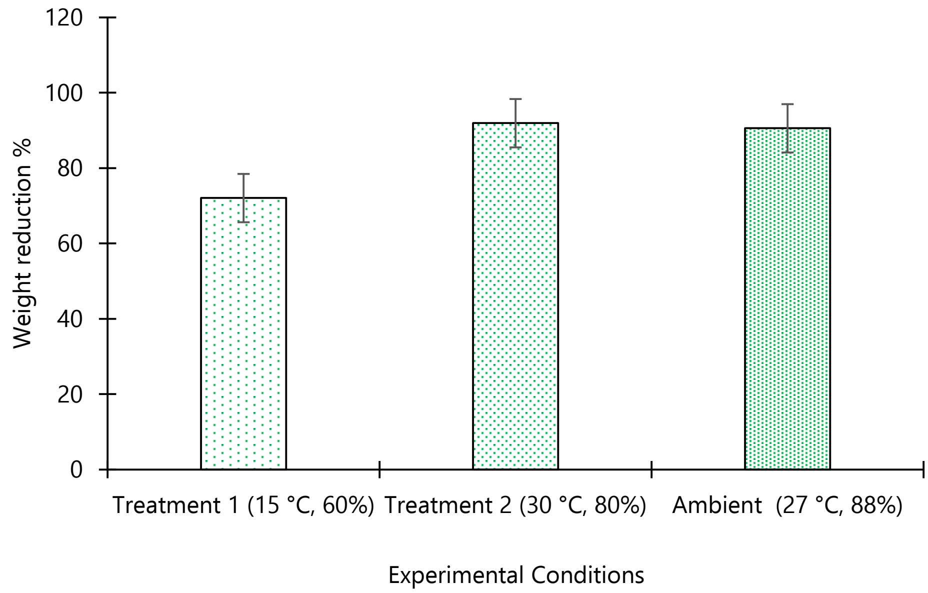

Figure 4. Weight reduction percentage of the water spinach leaves

Treatment 1, maintained at 15 °C with 60% relative humidity, exhibited the lowest weight reduction percentage. In comparison, Treatment 2, conducted at 30 °C and 80% relative humidity, showed a higher weight reduction percentage, reflecting accelerated water loss at the elevated temperature. The ambient condition (27 °C, 88% relative humidity) resulted in a weight-reduction percentage similar to that of Treatment 2.

Chlorophyll Reduction of the Water Spinach Leaves

Figure 5 shows the total chlorophyll changes in water spinach leaves under different experimental conditions. The chlorophyll content in water spinach decreased with storage time. Xanthopoulos *et al.*, (2016) also indicated that Romaine lettuce (*Lactuca sativa* var. longifolia), Savoy spinach (*Spinacia oleracea*), and rocket (*Eruca sativa* Mill) leaves exhibit chlorophyll degradation during storage [26]. Treatment 1, conducted at 15 °C with 60% relative humidity, showed the lowest chlorophyll degradation, indicating that cooler temperatures and moderate humidity help preserve chlorophyll content. In contrast, Treatment 2, maintained at 30 °C with 80% relative humidity, showed the highest chlorophyll degradation. The ambient condition (27 °C, 88% relative humidity) showed intermediate chlorophyll changes, suggesting that while high humidity can contribute to chlorophyll degradation, slightly lower temperatures than in Treatment 2 may reduce the rate of chlorophyll loss.

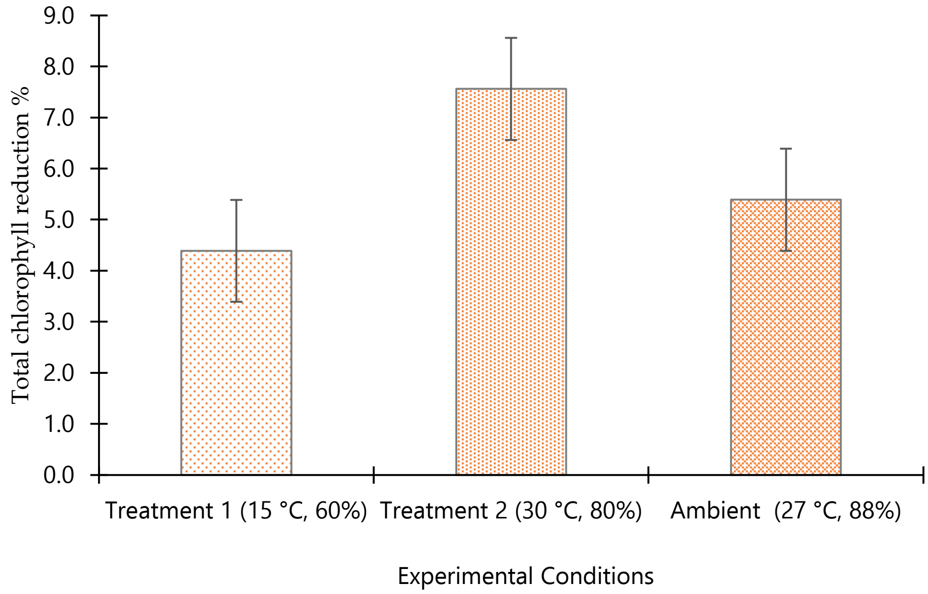

Figure 5. The chlorophyll reduction in the water spinach leaves

Color Changes* (ΔE) *and Hue Angle of the Water Spinach Leaves

Table 5 shows the color changes (ΔE) and Hue angle of water spinach leaves under different experimental conditions, indicating the extent of color degradation influenced by storage environments. Treatment 1 (15°C, 60% relative humidity) exhibited the least color change, with a ΔE value of 3.596 ± 1.65. This suggests that cooler temperatures and lower humidity effectively minimize the breakdown of chlorophyll and maintain the visual quality of the leaves.

Treatment 2 (30 °C, 80% relative humidity) showed a moderate color change, with a ΔE value of 5.805 ± 1.71, reflecting the impact of elevated temperatures and higher humidity on the color stability. Ambient conditions (27 °C, 88% RH) resulted in the highest color change, with a ΔE value of 17.15 ± 1.07, indicating that the combination of high temperature and humidity significantly accelerates chlorophyll degradation and color loss.

Table 5. The color changes and Hue angle of water spinach leaves

Experimental Conditions	**Color changes (ΔE)**	**Hue angle (h°)**	
		Initial	Final
Treatment 1 (15 °C, 60%)	3.596±1.65	72.41	77.69
Treatment 2 (30 °C, 80%)	5.805±1.71	67.36	82.59
Ambient (27 °C, 88%)	17.15±1.07	71.30	85.99

Surface color is one of the most visually appealing characteristics, and the lightness and hue angle are proportional to the amount of chlorophylls in the tissue. Table 5 indicates the initial and final hue angle of water spinach leaves under different conditions.

Standard Color Chart Method

Table 6 presents changes in water spinach leaf color during storage, as assessed using standard color charts. Initially, moderate olive green (137A) leaves were used for the experiments. Color differences were observed every 24 hours. In Treatment 1 (15 °C, 60% RH), by day 4, the leaves had become moderately yellowish-green (138 A), indicating slower color deterioration under cooler storage conditions. In Treatment 2 (30 °C, 80% RH), the leaves started as moderate olive green (137 A) and changed to moderate yellow-green (146 D) by day 4. The most rapid color degradation occurred under ambient conditions (27 °C, 88% RH), where the leaves transitioned from moderate olive green (137 A) to light olive (152 A), indicating significant pigment loss and a decline in quality due to high humidity and temperature.

Table 6. The color of the water spinach leaves assessed using a standard color chart

Days	Treatment 1 (15 °C, 60%)	Treatment 2 (30 °C, 80%)	Ambient (27 °C, 88%)
Initial	moderate olive green 137 A	moderate olive green 137 A	moderate olive green 137 A
1	moderate olive green 137 B	moderate olive green 137 B	moderate yellow green 137 C
2	moderate yellow green 137 C	moderate yellow green 146 B	moderate yellowish green 137 D
3	moderate yellowish green 137 D	moderate yellow green 146 C	moderate yellow green 138 C
4	moderate yellowish green 138 A	moderate yellow green 146 D	Light olive 152 A

Visual Method

Figure 6 shows the visual color of the water spinach leaves across the four days of observation under different treatments. The relevant score values are shown in Table 2. According to the results, the leaves were initially dark green. Treatment 1 (15 °C, 60%) consistently maintained the lowest color scores throughout the study, indicating a slower color change.

Treatment 2 (30 °C, 80%) and the ambient condition (27 °C, 88%) showed similar trends in the initial days, but from day 2 onwards, the ambient condition resulted in higher color scores, which peaked on day 4. This suggests that the ambient condition may have accelerated deterioration in leaf visual quality compared to the other treatments. The results highlight the influence of environmental conditions on the visual color of water spinach leaves during storage.

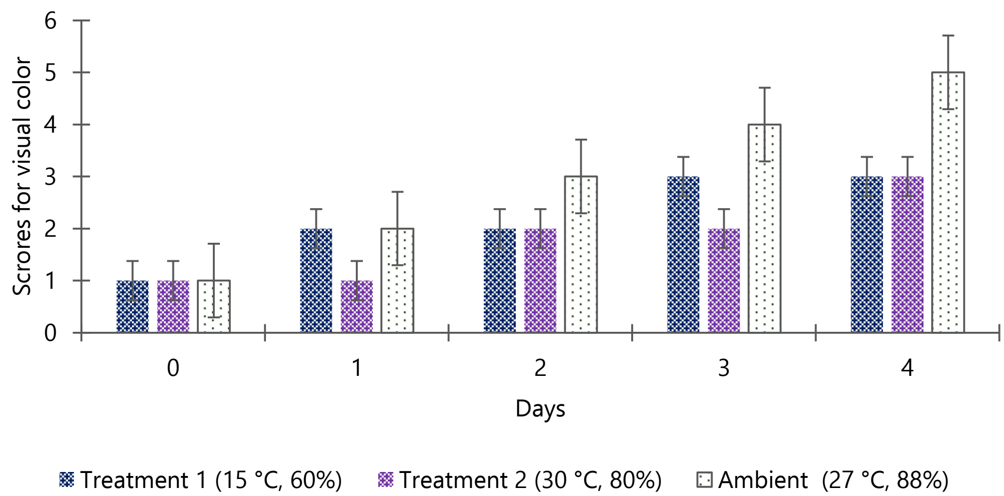

Figure 6. The visual color scores of the water spinach leaves (score values)

Visual Quality and Wilting of Water Spinach Leaves

Figure 7 shows the visual quality of water spinach leaves under different storage conditions over 4 days. The corresponding visual quality scores are presented in Table 2. Initially, there were no signs of deterioration, and the leaves remained excellent. Over time, Treatment 1 (15 °C, 60%) consistently maintained lower visual quality scores than the other treatments, indicating slower degradation. In contrast, Treatment 2 (30 °C, 80%) and the ambient condition (27 °C, 88%) showed higher scores from day 2 onward. The similarity between Treatment 2 and ambient conditions suggests that elevated temperatures accelerate deterioration in leaf visual quality. The results indicate that cooler storage conditions (as in Treatment 1) are more effective at preserving the visual quality of water spinach leaves over time. Similarly, Sanchez *et al.*, (2021) reported that different storage conditions significantly affect the quality and shelf life of sweet potato roots regardless of variety [27].

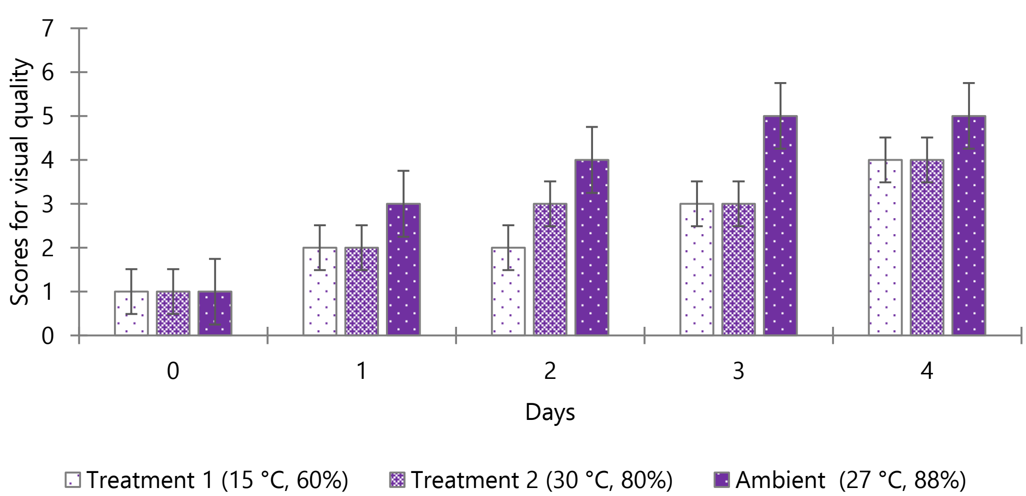

Figure 7. The visual quality of the water spinach leaves (score values)

Figure 8 illustrates the wilting of water spinach leaves under different storage conditions over 4 day period. Table 4 shows the corresponding wilting scores for water spinach leaves. The no-wilting initial quality leaves were used for the experiment.

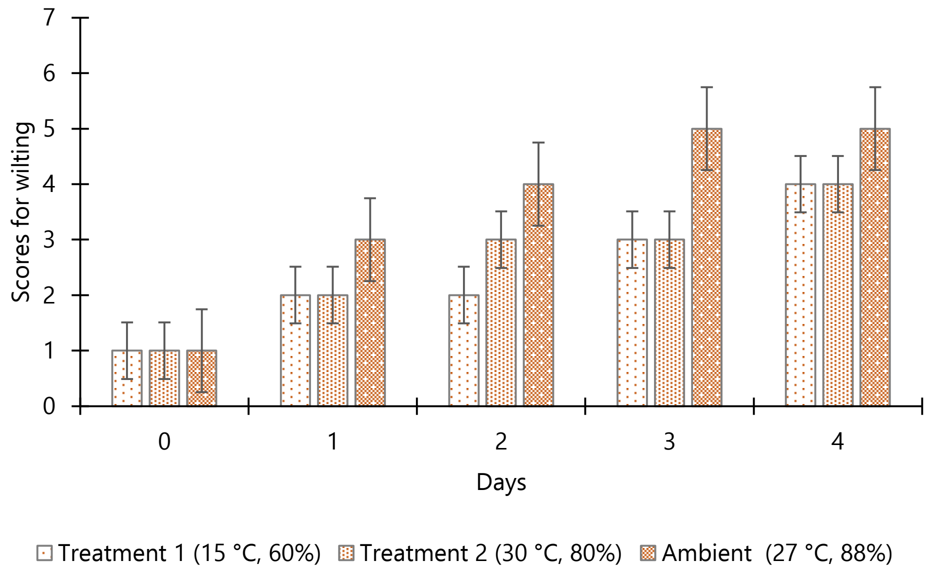

Figure 8. The wilting of water spinach leaves (score values)

Throughout the storage period, Treatment 1 (15 °C, 60%) consistently showed lower wilting than the other treatments, indicating slower degradation. Conversely, Treatment 2 (30 °C, 80%) and the ambient condition (27 °C, 88%) showed higher scores from day 2 onwards.

Conclusion

The rapid postharvest deterioration of leafy vegetables such as water spinach (*Ipomoea aquatica*) is mainly due to their high moisture content, which limits shelf life and marketability. Although the benefits of cooler storage for leafy greens are known, specific quantitative data on water spinach under controlled temperature and humidity conditions are limited. This study systematically evaluates how storage temperature and relative humidity affect key postharvest quality parameters of water spinach. Results show that storing at 15 °C and 60% RH minimizes weight loss and chlorophyll breakdown, with ΔE values indicating better color retention than at ambient or higher temperatures. Conversely, storage at ambient conditions accelerates aging, leading to greater moisture loss and a decline in visual quality. These findings not only support general cold storage principles but also provide evidence-based crop-specific storage conditions for water spinach, a species often overlooked in postharvest research. The results have practical implications for improving postharvest handling in resource-limited or tropical areas, thereby extending shelf life, reducing food waste, and strengthening supply chain sustainability for underutilized leafy vegetables.

Conflicts of Interest

The authors have no conflict of interest.

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