



Article

## Sustainable Strategies for Improving Growth, Productivity, And Storage Quality Using Ascorbic Acid and Potassium Humate in Two Lettuce Cultivars (*Lactuca sativa* L.)

Badran S. Agha\*, Muhanad A. Ahmad and Angham Talal Mahmoud Al-Chalabi



Department of Horticulture and Landscape Design, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq.

<https://doi.org/10.37229/fsa.fjb.2026.03.07>

\*Corresponding author: [badran.sabhan@uomosul.edu.iq](mailto:badran.sabhan@uomosul.edu.iq)

### Future Science Association

Available online free at  
[www.futurejournals.org](http://www.futurejournals.org)

Print ISSN: 2572-3006

Online ISSN: 2572-3111

Received: 15 January 2026

Accepted: 2 February 2026

Published: 7 March 2026

**Publisher's Note:** FA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Abstract:** The University of Mosul's Vegetable Field was the site of research for the 2024-2025 growing season to assess the impact of ascorbic acid and potassium humate foliar application on growth, yield and physiological characteristics of two cultivars of lettuce (Rama and Nader). The experiment was made up of three factors, namely, ascorbic acid which was applied at three concentrations (0, 100 and 150 mgL<sup>-1</sup>), potassium humate applied at two concentrations (0 and 2 g L<sup>-1</sup>) and two lettuce cultivars. The experiment was arranged in a randomized complete block design with three replications. The vegetative growth parameters, yield components, chlorophyll content, dry matter, protein, total soluble solids (TSS) and weight loss was recorded before and after cold storage for 21 days. The findings of the study reveal that mulching with wheat straw at 4-ton ha<sup>-1</sup> along with the application of *Pseudomonas fluorescens* at 15 kg ha<sup>-1</sup> was effective in controlling the disease and produced economic returns from white rust affected mustard. According to the research, all treatments of phosphorus and potassium had an effective impact on the improvement of the quality of Rama better than Nader on the traits of TSS, nitrogen, protein, potassium contents, and dry matter. The growth, yield and postharvest leaf quality were appreciably improved by the three-way interactions of ascorbic acid, potassium humate and cultivars. The use of ascorbic acid and potassium humate can act as an efficient and sustainable approach to enhancing physiological performance and the productivity and marketable quality of leafy vegetables. Moreover, it could boost nutrition and cut postharvest losses. Thus, it is a new practical strategy related to the use of biostimulants.

**Key words:** Ascorbic acid, potassium humate, lettuce, productivity, postharvest quality, sustainable strategy.

### 1. Introduction

Lettuce is a vegetable of species, *Lactuca sativa* L., one of the most important vegetables of the Compositae (Asteraceae) family. Common Name: Lettuce. The family has approximately 800 genera

and nearly 20,000 species that are predominantly annual or perennial herbs. Nevertheless, there are some woody types too. This plant family is one of the largest. Lettuce is cultivated primarily for its leafy greens. Consequently, it is a valuable salad vegetable. Lettuce offers numerous health benefits and is very nutritious (**Hassan, 2003**). Research suggests that 100 g of lettuce leaves contains 94 g water, 18 kcal, 1.3 g protein, 0.3 g fat, 3.5 g carbohydrates, 0.7 g fiber and 0.9 g ash. Lettuce, a member of the Asteraceae family, is composed of leaves. In North America, it is classified as a leaf vegetable; in South Asia, it is categorized as a salad vegetable; in Europe, it is classified as a green vegetable; while in almonds, it is classified as a seed vegetable. The varied nutrients found in lettuce show its biological function as a source of vitamins and minerals for human health. This shows that lettuce has gained importance in achieving healthy meal preparation and healthy diet (**Kim *et al.*, 2016**). Because lettuce is a very productive leafy vegetable which contains high nutritional value, the physiological and nutritional factors and modern agricultural practices like the application of an antioxidant and biostimulator have become the point of interest to enhance its growth, yield and postharvest quality. Such tactics facilitate achieving market requirements and promote agricultural sustainability. One important factor is postharvest quality, which determines its storability, transportability and marketability. This a crucial factor that determines its consumer shelf life and sensory properties (**Kader, 2002**). Earlier studies claim that varietal differences markedly affect resistance to water loss, colour changes, and enzyme activity during cold storage. This emphasizes the importance of choosing varieties that are highly tolerant (**Wills *et al.*, 2026**).

Plants' important antioxidant is ascorbic acid or vitamin C. The cell is protected from reactive oxygen species; it improves photosynthetic efficiency; the structure of chlorophyll is preserved and regulating the activities of enzymes involved in growth & development processes. According to **Smirnoff (2018)**, it also effective in reducing the loss of moisture and delaying physiological deterioration thereby improving the vegetative growth and postharvest quality of the leafy vegetable. In Egypt, experiments conducted by **El Sayed and Ahmed (2013)** reported that 100 mg L<sup>-1</sup> added to the plant in two growing season significantly improved the vegetative growth traits of lettuce including plant height as well as number of leaves. Ascorbic acid improves plant productivity. This treatment enhanced quality parameters of 0.5 mM ascorbic acid spray and increased nitrogen and protein content of leaves. The recent study by **El Shawy *et al.*, 2019** confirmed that a moderate level of ascorbic acid foliar application can enhance vegetative growth of leaf lettuce plants. Plus, it works by enhancing antioxidant system activity and that directly helps to aid the vital physiological processes within the plant. Rady *et al.* found that ascorbic acid application at 400 mg L<sup>-1</sup> positively influenced the growth and yield of lettuce as evident by increased leaf length, number of leaves and fresh weight per plant. The growth of the plants improved as ascorbic acid bolstered the antioxidant defence system while aiding essential physiological processes, thereby improving productivity and growth. According to **Abdullah *et al.* (2023)**, pre-storage treatment of lettuce with ascorbic acid solutions was able to prolong the shelf life of the crop. The treatment has reduced weight loss and delayed wilting symptoms leading to better visual appearance and marketability than untreated controls. Through simple pre-storage chemical treatments, the study can help to improve the postharvest stability and shelf life. **Naz *et al.* (2024)** found that 100 and 400 mg L<sup>-1</sup> foliar application of ascorbic acid had a significant effect on leaf number and leaf area of lettuce plants which resulted in improved vegetative growth over control treatments. Enhanced antioxidative activities and photorespiratory efficiency led to increased biomass accumulation and physiological performance improvement in bioengineered rice. According to a paper by **Atala *et al.* (2025)**, lettuce heads dipped in ascorbic acid solutions were found to lose less weight, maintain better green colour, and slow down oxidative enzyme activity during cold storage at 0 °C. Also, after being cut, the samples stayed fresh dFor.

Ascorbic acid helped to maintain physiological and visual quality of lettuce held under 12 days of cold storage that can increase lettuce marketing period.

A potassium humate is a biostimulant of great significance and with high physiological activity. It potassium humate has been reported to enhance the efficiency of uptake of nutrients as well as root growth and stimulate the activity of microorganisms in the rhizosphere being its influence beneficial to the tissues' vigor and the final product's quality (**Canellas & Olivares, 2014; Rouphael and Colla, 2020**). According to **Trevisan *et al.* (2010)**, potassium humate can enhance the storage quality and

longevity of lettuce. The application of such products may be linked to a decrease in water loss rates and a delay in physiological damage. Potassium humate is a product of sustainable agriculture which can be used for improving resource efficiency and reducing postharvest losses in production systems. This product may improve postharvest quality and tolerance to storage and transport (**Rouphael and Colla, 2020**).

Potassium humate promotes the tolerance against drought, salinity stress, heavy metal contamination and thermal stresses (particularly under cold storage conditions) in crops. This happens through various integrated mechanisms, enhancing membrane stability and activating cellular protective systems. Humic substances provide a better environment for plants to cope with stresses. Additionally, these substances boost the efficacy of enzymes that combat oxidation. They also keep hormones in check, allowing things to run smoothly. Plus, they inhibit the breakdown of cells even when the going gets tough. Accordingly, recent studies have shown that potassium humate application enhances cation exchange capacity and increases the uptake and accumulation of minerals. Improvements to the nutritional content of horticultural crops strengthens the tissues' resistance to physiological damage that usually occurs when the fresh produce is delivered fresh and cold-stored. This helps in retaining the membrane integrity in such a way that it will limit the loss of important substances from the fruit or vegetable. This improvement enhances the shelf life and quality of the fruits. Humic acid association Researchers **Mahmood *et al.* (2022)** found potassium fertilizer with humic acid at 50, 100 and 150 mg L<sup>-1</sup> showed maximum vegetative growth in lettuce for all traits. The researchers also observed that 2 g L<sup>-1</sup> of calcium-chloride gave maximum results as well as freshly harvested leaf. The most effective responses were observed at elevated levels of humic acid and potassium, which is beneficial for better availability and uptake of nutrients, especially potassium. In the same way, improved physiological processes may yield better results for photosynthesis. As per **Khalil and Moustafa (2022)**, biomass yield and quality attributes of spinach improved with the additional supplement of humic substances and ascorbic acid through foliar application which probably occurred in lettuce as well. According to Omar *et al.*, using higher amounts of humic acid through leaves is believed to increase plant height and chlorophyll content of lettuce. Moreover, **Sawsan and Saeed (2020)** indicated that potassium humate application (0, 3 and 6 g L<sup>-1</sup>) via foliar application on lettuce cultivars Polaris and Nader improved vegetative growth as well as quality traits of lettuce. In addition, the most effective concentration was 3 g L<sup>-1</sup>.

A significant increase was observed in leaf length, number of leaves, fresh weight, chlorophyll and TSS due to nutrient availability and photosynthesis efficiency. Also, as reported by **Ozfidan-Konakci *et al.* (2018)**, humic substances promote the activities of antioxidant enzymes which are the main stress-response proteins to prevent the damage caused by free radicals including superoxide dismutase, catalase and ascorbate peroxidase. With the enhancement of this enzyme, the integrity of the membrane and the stability of proteins are preserved, while oxidative processes and physiological deterioration are reduced, thus leading to improved postharvest quality and shelf life of lettuce.

## 2. Materials and Methods

### 2.1. Experimental site, land preparation, planting, and cultural practices

The study's experimental field was the vegetable field of the College of Agriculture and Forestry University of Mosul during the season of study 2024–2025. After two orthogonal operations were ploughed on disc plough, the land was level and made smooth with harrow for uniform soil surface. The research's experimental units were then made of a trio of ridges wherein the experimental unit had an area of 1 m<sup>2</sup>. Every ridge consisted of three planting rows spaced 35 cm apart from each other and subsequently 35 cm apart from each other. So, one experimental unit contained a total of nine plants.

The two lettuce cultivars used in this study were Rama and Nader. It is possible to sow seeds on a seedling tray on 20 September 2024. The transplanting of seedlings in the fields was done in the early morning with seven days of hardening. At the stage of 3-4 true leaf stage. The soil was moist at the time of transplanting. All agricultural interventions were applied indiscriminately on all the experimental units which included irrigation, fertilization, weeding and preventive pest and disease control.

The soil was applied with 150 kg ha<sup>-1</sup> of compound fertilizer (NPK 15-15-15) equivalent to 15 g per experimental unit one week after transplanting. According to Hassan (2003), shallow trenches were dug on either side of each plant to place the fertilizer, which later on was covered with soil.

## 2.2. Experimental factors and design

**The study included three factors:**

1. Ascorbic acid was sprayed on the leaves at three different concentrations (0, 100, 150 mg L<sup>-1</sup>).
2. The research utilized two diverse concentrations of potassium humate foliar application (0 and 2 g L<sup>-1</sup>).
3. The **Rama** cultivar of lettuce and other **Nader** cultivars.

Three applications of foliar spraying were conducted early morning. The experiment was laid out in a randomized complete block design with three replications per treatment. SAS software's statistical analyses were done of the data. As mentioned by **Al-Rawi and Khalaf Allah (2000)**, Duncan's multiple range test was carried out subsequently to mean comparisons.

## 2.3. Harvesting and cold storage

Lettuce plants of the **Rama** and **Nader** cultivars were carefully harvested at the full-head stage, ensuring the integrity of the leaves and heads. For each experimental unit, data were recorded on growth traits, yield components, and postharvest quality characteristics.

The harvested plants were stored in refrigerated conditions at 1 ± 1 °C and 90–95% relative humidity for 21 days, placed in perforated bags throughout the storage period to ensure proper ventilation and maintain product quality.

## 2.4. Studied traits

**Total number of leaves (leaves plant<sup>-1</sup>):** The total number of leaves per plant was recorded, excluding very small leaves located at the apical meristem.

**Plant height (cm plant<sup>-1</sup>):** Plant height was measured from the soil surface to the tip of the highest leaf using a measuring tape. Measurements were taken from five plants, and the mean value was calculated.

**Average head weight (g plant<sup>-1</sup>):** Head weight was determined by dividing the total weight of harvested heads from each experimental unit by the number of heads produced.

**Yield per experimental unit (kg experimental unit<sup>-1</sup>):** Total yield per experimental unit was calculated by summing the weights of all heads harvested from the experimental unit, which consisted of nine plants.

**Total yield (t ha<sup>-1</sup>):** Total yield was calculated by dividing the yield per experimental unit by the experimental unit area and multiplying the result by 10,000.

**Total chlorophyll content in leaves (SPAD units) before and after storage:** Leaf chlorophyll content was measured using a SPAD-502 chlorophyll meter. Ten readings were taken at different positions on the leaves of each plant, and the average value was calculated.

**Dry matter percentage in lettuce leaves before storage (%):**

$$\text{Dry matter (\%)} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times 100$$

**Total soluble solids (TSS%) before and after storage:** TSS% was estimated using a handheld refractometer according to the method described by **AOAC (2000)**.

**Weight loss percentage (%):** Weight loss was calculated using the following equation:

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

**Leaf nitrogen and potassium contents before and after storage:** Nitrogen content was determined after digestion using the method described by **Black (1965)**, while potassium content was determined according to the method reported by **Richards (1954)**.

**Leaf protein content before and after storage:** Protein content was calculated based on the percentage of nitrogen in the leaves using the following equation:

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times 6.25 \text{ (Mitrus *et al.*, 2003)}.$$

### 3. Results and Discussion

According to the data from table (1), the count of leaves was maximum with a treatment of ascorbic acid as compared to the control. The control generated the mean lowest number of leaves while treatments with 150 mg L<sup>-1</sup> produced the mean highest number of leaves. There were significantly more leaves as a result of potassium humate spraying (2 g L<sup>-1</sup>) than without spraying treatment. When it comes to cultivar effect, Rama cultivar produced significantly higher leaves compared to Nader cultivar. The cultivars of ascorbic acid and potassium humate influenced the number of leaves considerably. The Rama cultivar that received the interaction between 150 mg L<sup>-1</sup> ascorbic acid and 2 g L<sup>-1</sup> potassium humate produced the to obtain the highest average number of leaves. The control treatment on Nader cultivar generated the lowest number of leaves on average.

**Table (1). The foliar application of ascorbic acid and potassium humate and their interaction effect on the leaf number of two lettuce cultivars**

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	34.33 e	31.66 f	33.00 d	36.67 c
	2	43.00 c	37.66 d	40.33 c	
100	0	41.33 c	37.33 d	39.33 c	41.25 b
	2	48.00 b	38.33 d	43.16 b	
150	0	41.33 c	37.33 d	39.33 c	43.50 a
	2	54.00 a	41.33 c	47.6 <sup>y</sup> a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	38.67 c	34.67 d	Mean effect of potassium humate	
	100	44.67 b	37.83 c		
	150	47.67 a	39.33 c		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	39.00 b	35.44 c	37.22 b	
	2	48.33 a	39.11 b	43.72 a	
Mean effect of cultivars		43.67 a	37.28 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

As per table (2), The application of ascorbic acid at a concentration of 150 mg L<sup>-1</sup> through foliage caused a significant enhancement in the height of plants as compared to the control treatment. On the other hand, potassium humate spray at a concentration of 2 g L<sup>-1</sup> on the leaves considerably raised the height of the plant in comparison to untreated plants. According to the findings of the research, Rama cultivar has a greater plant height as compared to Nader cultivar. The experiment analysed the effect of ascorbic acid and potassium humate on the plant height of french beans. The result for the best ascorbic acid (150 mg L<sup>-1</sup>) and potassium humate (2 g L<sup>-1</sup>) was obtained for Rama cultivar for get highest mean plant height.

**Table (2).** The influence of spraying ascorbic acid and potassium humate, as well as their interaction, on the height (cm) of two lettuce varieties

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	30.17 cde	28.17 f	29.17 c	29.62 b
	2	30.67 bcd	29.50 def	30.08 c	
100	0	31.67 bc	28.83 ef	30.25 c	31.00 a
	2	32.17 b	31.33 bc	31.75 b	
150	0	31.00 bcd	29.00 ef	30.00 c	31.47 a
	2	33.67 a	32.00 b	32.83 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	30.47 b	28.83 c	Mean effect of potassium humate	
	100	31.97 a	30.08 b		
	150	32.33 a	30.50 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	30.94 b	28.67 c	29.86 b	
	2	32.17 a	30.94 b	31.56 a	
Mean effect of cultivars		31.56 a	29.86 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (3).** The impact of spraying ascorbic acid and potassium humate, as well as their interaction, on chlorophyll content (SPAD) prior to storage on two lettuce cultivars.

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	41.67 d	39.33 e	40.50 c	42.67 b
	2	44.90 bc	44.80 bc	44.85 b	
100	0	44.90 bc	43.63 cd	44.27 b	45.55 a
	2	46.70 ab	47.00 ab	46.85 a	
150	0	44.93 bc	44.17 c	44.55 b	45.89 a
	2	47.60 a	46.87 ab	47.23 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	43.28 b	42.07 b	Mean effect of potassium humate	
	100	45.80 a	45.37 a		
	150	46.27 a	45.57 a		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	43.83 b	42.38 c	43.10 b	
	2	46.40 a	46.22 a	46.31 a	
Mean effect of cultivars		45.17 a	44.30 a		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

According to data in Table (3), the effect of different concentrations of ascorbic acid of 100 and 150 mg L<sup>-1</sup> foliar treatment significantly increased the leaf chlorophyll content as compared to control treatment whose values were lowest. When compared to the control, application of potassium humate at a concentration of 2 g L<sup>-1</sup> through the foliar method significantly increased the chlorophyll content of lettuce leaves. Rama cultivar possessed considerably more chlorophyll compared to Nader cultivar

when evaluated for cultivar effect on chlorophyll. The Rama cultivar showed the maximum chlorophyll content when 150 mg L<sup>-1</sup> ascorbic acid and 2 g L<sup>-1</sup> potassium humate were used. In contrast, the Nader cultivar's control treatment recorded the lowest chlorophyll content values.

The tables show (4-6) that the foliar application of 150 mg L<sup>-1</sup> ascorbic acid significantly increased all yield traits (head weight g plant<sup>-1</sup>, yield per experimental unit kg, total yield t ha<sup>-1</sup>) in comparison to the control treatment that showed the lowest values. The yield attributes were significantly better in the treatment with potassium humate 2 g L<sup>-1</sup> as there was a foliar spray. The performance of Rama cultivar was better than that of Nader cultivar according to data from three tables all yield attributes. All yield characters exhibited synergistic effects of interaction between ascorbic acid, potassium humate copies and cultivars. The treatment of Rama cultivar with 150 mg L<sup>-1</sup> ascorbic acid and 2 g L<sup>-1</sup> potassium humate (KH) gave the highest productivity with 727.67 g head<sup>-1</sup>, 6.5490 kg per experimental unit, and, 65.490 t ha<sup>-1</sup> respectively. Conversely, the control treatment of the Nader cultivar had the lowest values recorded. The tables (1-6), suggest that due to the role of ascorbic acid a vital role in improving photo assimilatory and growth efficiency under stress. According to **Pignocchi and Foyer (2003)** and **Smirnoff (2018)**, as an antioxidant ascorbic acid protects the structure of cell membranes and chlorophyll pigments, and it also has a role in stimulating cell division and elongation through its effects on enzymes involved in the cell wall, which produces a positive effect on vegetative growth and productivity. Potassium humate improves cuticle properties to help reduce water loss so that the loss of surface water can become less and less. According to a study conducted by **Taiz *et al.* (2015)**, lettuce and other leafy vegetables also need this. Based on research, Rama cultivar of pumpkin has more superior quality than Nader cultivar due to genetic difference. The rate at which cells divide, elongate, and develop tissue activity differs among cultivars. The differences in biomass accumulation as well as efficiencies of photosynthesis and nutrient uptake enhance the accumulation of sugar and dry matter in leaves and enhancement of yield (**Evans, 2013; Taiz *et al.*, 2015**).

**Table (4). Impact of foliar spraying ascorbic acid and potassium humate and their interaction on head weight (g) of two lettuce cultivars.**

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	510. gh	485.67 h	497.83 d	563.47 c
	2	651.33 b	606.67 cd	629.00 b	
100	0	590.00 de	540.33 fg	565.17 c	596.58 b
	2	626.00 bcd	630.00 bc	628.00 b	
150	0	600.67 cd	564.00 ef	582.33 c	634.33 a
	2	727.67 a	645.00 b	686.33 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	580.67 c	546.17 d	Mean effect of potassium humate	
	100	608.00 b	585.17 bc		
	150	664.17 a	604.50 bc		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	566.89 c	530.00 d	548.44 b	
	2	668.33 a	627.22 b	647.78 a	
Mean effect of cultivars		617.61 a	578.61 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (5).** A study to determine the effect of foliar application of ascorbic acid and potassium humate and their interaction on yield per experimental unit (kg) of two lettuce cultivars

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	4.59 gh	4.37 h	4.48 d	5.070 c
	2	5.86 b	5.46 cd	5.66 b	
100	0	5.31 de	4.86 fg	5.08 c	5.369 b
	2	5.63 bcd	5.67 bc	5.65 b	
150	0	5.40 cd	5.07 ef	5.24 c	5.709 a
	2	6.54 a	5.80 b	6.17 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	5.22 c	4.91 d	Mean effect of potassium humate	
	100	5.47 b	5.26 bc		
	150	5.97 a	5.45 bc		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	5.10 c	4.77 d	4.93 b	
	2	6.01 a	5.64 b	5.83 a	
Mean effect of cultivars		5.55 a	5.20 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (6).** Impact of surface application of ascorbic acid and potassium humate and their interaction on total yield (t ha<sup>-1</sup>) of two lettuce cultivars

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	45.90 gh	43.71 h	44.80 d	50.70 c
	2	58.62 b	54.60 cd	56.61 b	
100	0	53.10 de	48.63 fg	50.86 c	53.69 b
	2	56.34 bcd	56.70 bc	56.52 b	
150	0	54.06 cd	50.76 ef	52.41 c	57.09 a
	2	65.49 a	58.05 b	61.77 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	52.26 c	49.15 d	Mean effect of potassium humate	
	100	54.72 b	52.66 bc		
	150	59.77 a	54.4 bc		
Potassium humate (g L <sup>-1</sup> ) × Cultivars	0	51.02 c	47.70 d	49.36 b	
	2	60.15 a	56.45 b	58.30 a	
Mean effect of cultivars		55.58 a	52.07 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

According to the data presented in Table (7), the dry matter percentage of lettuce leaves under the treatments in the control significantly surpassed that of treatments in ascorbic acid. The highest values recorded as  $150 \text{ mg L}^{-1}$  followed by those with  $100 \text{ mg L}^{-1}$ . The increase may result from ascorbic acid's stimulation of the concentration of enzymes related to the synthesis of carbohydrates and proteins thus speeding up the efficiency of dry matter accumulation in leaves. **El-Bassiouny and Sada 2015** (have found that ascorbic acid is also useful for nitrogen metabolism and protein formation, which constitute a major part of dry matter. The results indicate that foliar application of potassium humate at the dose of  $2 \text{ g L}^{-1}$  increases the percentage of leaf dry matter compared to untreated plants. There could be a reason for this rise. Humates play a key role in improving the use and uptake of nitrogen and potassium nutrients. With the help of humates, the cation exchange capacity in the root zone increases.

Both copper and zinc are nutrients that help synthesize the different proteins and carbohydrates of the plant which leads to a greater accumulation of dry matter in the leaves. There was a significant difference in dry matter percentage of Rama and Nader cultivars. Rama shown this superiority due to having higher chlorophyll content and improved photosynthetic enzyme activity which gets transposed on dry matter production. **(Evans, 2013)**. There was a significant interaction of ascorbic acid, potassium humate and cultivars. The highest percentage of dry matter was obtained from Rama plant using  $150 \text{ mg L}^{-1}$  ascorbic acid and  $2 \text{ g L}^{-1}$  potassium humate, while the control of Nader cultivar recorded the lowest value. When the non-participant received both treatments, their physiological status improved, and he accumulated more dry matter than stored. The two treatments have a synergistic effect.

**Table (7). Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf dry matter percentage of two lettuce cultivars before storage**

Effect of foliar application of ascorbic acid ( $\text{mg L}^{-1}$ )	Effect of foliar application of potassium humate ( $\text{g L}^{-1}$ )	Cultivars		Ascorbic acid $\times$ potassium humate ( $\text{g L}^{-1}$ )	Mean effect of ascorbic acid foliar application ( $\text{mg L}^{-1}$ )
		Rama	Nader		
0	0	2.73 e	2.65 e	2.69 c	2.92 c
	2	3.23 d	3.06 d	3.15 b	
100	0	2.84 e	2.73 e	2.78 c	3.35 b
	2	4.03 a	3.80 b	3.91 a	
150	0	3.45 c	3.10 d	3.27 b	3.56 a
	2	4.06 a	3.63 bc	3.85 a	
Ascorbic acid ( $\text{mg L}^{-1}$ ) $\times$ Cultivars	0	2.98 d	2.86 d	Mean effect of potassium humate	
	100	3.43 b	3.26 c		
	150	3.76 a	3.36 bc		
Potassium humate ( $\text{g L}^{-1}$ ) $\times$ Cultivar	0	3.01 c	2.83 d	2.92056 b	
	2	3.77 a	3.50 b	3.63889 a	
Mean effect of cultivars		3.39 a	3.16 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

According to table (8), the storage of leaves caused a significant reduction in chlorophyll content. The application of Ascorbic acid  $150 \text{ mg L}^{-1}$  (foliar application) significantly reduced this value as compared to  $100 \text{ mg L}^{-1}$  and control. It is possible that less oxidative stress leads to this chloroplast membrane protection. Vitamin C is a strong antioxidant, which might weaken the oxidation of chlorophyll. **(Noctor & Foyer 1998)** Leaf chlorophyll content of untreated plants was lowest after storage. Potassium humate infusion at  $2 \text{ g L}^{-1}$  could maintain leaf chlorophyll content after the storage

treatment. As **Canellas and Olivares (2014)** state, the reason for this effect may be enhancement of antioxidant enzymes SOD, CAT and APX, which reduces accumulation of ROS and preserves chlorophyll. According to the cultivars, 'Rama' had a higher chlorophyll content of the leaves during storage as compared to 'Nader'. It indicates improved genetic ability to withstand storage conditions and stay greening. The improved ability to produce antioxidants (like ascorbate, glutathione and antioxidant enzymes SOD, CAT and APX) (**Noctor & Foyer, 1998**) and higher leaf nitrogen and protein contents before storage (see Tables 12 and 13, respectively) may explain this superiority (**Marschner, 2012**).

The results of this study were significantly affected by the interaction of other elements. The highest chlorophyll content was recorded in the treatment using 150 mg L<sup>-1</sup> ascorbic acid with 2 g L<sup>-1</sup> potassium humate in the cultivar Rama post storage while minimum value was obtained from the control treatment of cultivar Nader.

**Table (8). The research assessed the influence of ascorbic acid and potassium humate, as well as their interaction, on chlorophyll content, as indicated by the SPAD measure, of two lettuce cultivars after cold storage**

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	36.40 bc	31.33 d	33.86 bc	33.08 c
	2	32.63 cd	31.66 d	32.15 c	
100	0	38.03 b	35.26 bcd	36.65 b	35.95 b
	2	37.53 b	32.96 cd	35.25 b	
150	0	37.83 b	35.60 bcd	36.71 b	42.32 a
	2	49.13 a	46.73 a	47.93 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	34.51 c	31.50 c	Mean effect of potassium humate	
	100	37.78 b	34.11 c		
	150	43.48 a	41.16 a		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	37.42 ab	34.06 c	35.74 b	
	2	39.76 a	37.12 b	38.44 a	
Mean effect of cultivars		38.59 a	35.59 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

Tables 9 and 10 illustrated the significant effect of foliar application of ascorbic acid and potassium humate as well as their interaction effect on the percentage of total soluble solids (TSS) before and after storage. Foliar applications of ascorbic acid at the rate of 150 mg L<sup>-1</sup> improved TSS significantly over control treatment which had lowest values. Potassium humate spraying (2 g L<sup>-1</sup>) also enhanced TSS with the untreated control showed the lowest values. The increase in the TSS percentage due to sprayed ascorbic acid and potassium humate is mainly owing to the improvement of photosynthetic efficiency and enhanced CO<sub>2</sub> fixation, which increases sugar production and thus the TSS percentage (**Smirnoff, 2018**). Furthermore, humates improve metabolic pathways and the accumulation of soluble compounds including amino acids and vitamins.

**Table (9).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on the percentage of total soluble solids (TSS) in the leaves of two lettuce cultivars before storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	2.14 ef	1.99 f	2.06 b	2.35 b
	2	2.73 a-d	2.53 b-f	2.63 a	
100	0	2.263 def	2.22 def	2.24 b	2.52 ab
	2	3.05 ab	2.56 b-e	2.81 a	
150	0	2.35 c-f	2.21 def	2.28 b	2.63 a
	2	3.17 a	2.81 abc	2.99 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	2.43 ab	2.26 b	Mean effect of potassium humate	
	100	2.66 a	2.39 ab		
	150	2.76 a	2.51 ab		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.25 c	2.14 c	2.19 b	
	2	2.98 a	2.63 b	2.81 a	
Mean effect of cultivars		2.61 a	2.39 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (10).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on the percentage of total soluble solids (TSS) in the leaves of two lettuce cultivars after storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	1.73 de	1.50 e	1.61 c	1.72 b
	2	1.86 cde	1.80 de	1.83 bc	
100	0	2.13 b-e	2.03 b-e	2.08 b	2.41 a
	2	3.01 a	2.48 abc	2.74 a	
150	0	2.29 bcd	2.10 b-e	2.20 b	2.53 a
	2	3.06 a	2.66 ab	2.86 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	1.80 b	1.65 b	Mean effect of potassium humate	
	100	2.57 a	2.25 a		
	150	2.68 a	2.38 a		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.05 bc	1.88 c	1.96 b	
	2	2.64 a	2.31 ab	2.48 a	
Mean effect of cultivars		2.35 a	2.09 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

TSS readings were higher (Trevisan, 2010). Pre-harvest, the Rama potato cultivar was significantly superior to the Nader cultivar in tuber dry matter content.

The combination of potassium humate and ascorbic acid and the cultivars proved superior in 2011. The interaction between Rama cultivar and 150 mg L<sup>-1</sup> ascorbic acid + 2 g L<sup>-1</sup> potassium humate showed high TSS %. The outcome showed a significant difference with different interaction treatments which showed treatment synergy in improving the trait. As storage went on, TSS values lowered as the respiration process consumed more sugar than the pre-storage phase. On the other hand, the values of the sprayed treatments were relatively higher than the control. This shows that treatments play a role, also at advanced storage time in reducing the TSS loss in storage (Trevisan 2010).

According to Table 11, treatment with ascorbic acid (150 mg L<sup>-1</sup>) declined weight loss, which was stated severely treatment. A powerful antioxidant, vitamin C prevents the accumulation of reactive oxygen species (ROS).

It causes a reduction in respiration rate and water loss. Furthermore, it maintains the structural integrity of cells from injuries. Moreover, Kader (2002) and Abdullah (2023) claim it has the potential to inactivate pectinase and cellulase activity that enhances tissue binding and water loss. Potassium humate at 2 g L<sup>-1</sup> significantly reduced weight loss in the untreated control group. The beneficial influence of alsil on the loss of water of plants is due to the action of alsil feed and its derivative penetration agent that said improve the water uptake plant through roots, increase the turgor pressure in plant cell and stabilized the cellular membrane (Canellas and Olivares, 2014). The study conducted by Nardi *et al.* in 2002 concluded that potassium humates enhance the strength of cell walls as well as lowering their water permeability.

**Table (11). Effect of foliar application of ascorbic acid and potassium humate and their interaction on percentage weight loss of two lettuce cultivars after cold storage**

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	5.54 b	6.93 a	6.23 a	5.22 a
	2	3.88 d	4.53 c	4.20 b	
100	0	3.67 d	2.90 e	3.28 c	3.06 b
	2	2.15 f	3.30 de	2.72 d	
150	0	2.80 e	3.53 d	3.18 c	2.39 c
	2	1.42 g	1.80 fg	1.61 e	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	4.71 b	5.73 a	Mean effect of potassium humate	
	100	2.90 c	3.10 c		
	150	2.11 d	2.68 c		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	4.06 b	4.46 a	4.23 a	
	2	2.48 d	3.21 c	2.85 b	
Mean effect of cultivars		3.24 b	3.83 a		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

With regards to the cultivars, Rama showed less weight loss after storage as compared to Nader. Rama has been found genetically better than Nader in terms of ability to tolerate water loss during storage and maintain firmness of head. Furthermore, the interaction of ascorbic acid, potassium humate and cultivars three-way interaction of was statistically significant. The treatment which resulted in the lowest weight loss was 150 mg L<sup>-1</sup> ascorbic acid + 2 g L<sup>-1</sup> potassium humate + Rama cultivar. Nevertheless, the control treatment with cultivar Nader showed the highest weight loss recorded.

**Table (12). Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf nitrogen content (%) of two lettuce cultivars before storage**

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	1.88 gh	1.77 h	1.83 e	2.06 c
	2	2.42 d	2.19 ef	2.30 c	
100	0	2.18 ef	2.04 fg	2.11 d	2.58 b
	2	3.06 c	3.06 c	3.06 b	
150	0	2.31 de	2.09 f	2.20 cd	2.78 a
	2	3.47 a	3.26 b	3.37 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	2.15 c	1.98 d	Mean effect of potassium humate	
	100	2.62 b	2.55 b		
	150	2.89 a	2.68 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.12 c	1.97 d	2.04 b	
	2	2.98 a	2.84 b	2.91 a	
Mean effect of cultivars		2.55 a	2.40 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

The tables 12 and 13 show the results on nitrogen and protein contents of lettuce leaves before storage were significantly increased due to their foliar application of ascorbic acid and potassium humate. In addition, a clear interaction was shown among the two and the effect of cultivars. As the nitrogen content of leaves increases, so does the protein content and application like foliar ascorbic acid at 150 mg L<sup>-1</sup> is statistically significant. As per the authors **Buch *et al.* (2018)** and **Malagoli *et al.* (2021)**, this beneficial influence arises from the involvement of ascorbic acid as an antioxidant, as well as a metabolic regulator. Later activates nitrogen reductase enzymes and boost the ability of the plant to utilize nitrogen in an efficient way since it translates nitrogen into assimilated amino acids, structural and functional proteins and also protects the cellular mechanism to be takes part in protein biosynthesis from oxidative degeneration enabling the improvement of metabolic processes related to protein synthesis. **Khan *et al.* (2021)** and **El-Beltagi *et al.* (2022)** also conclusion the same results. The study found that spraying a leaf of a plant species with a potassium humate solution at 2 g L<sup>-1</sup> produced good results. The humates are able to foster the growth of root systems, and increase their absorptive surface to augment the availability of nutrients in the rhizosphere specifically nitrogen. Humates can stimulate soil micro-organisms that benefit plants, and allow better nutrient uptake and fertilisers. Thus, soil became active. As a consequence of these combined effects, the uptake of nitrogen by leaves and its effectiveness in utilized for producing proteins is enhanced. (**Farooq *et al.*, 2023**; **Rose *et al.*, 2023**). The results of the study also revealed that nitrogen content and protein content of the leaves are positively related. This means that with the increase of nitrogen in the leaves there will be a significant increase in protein content. Since an improved nitrogen nutrition is an essential factor in improving the nutritional value of the plant. Among the cultivars, Rama was found to contain more nitrogen and protein than Nader. A likely genetic difference probably exists between cultivars in their capacity for N uptake efficiency, with Rama having a greater ability to convert N to important organic compounds than Nader. The literature reviews indicate that the variances amongst cultivars for their nitrogen and protein contents which caused differences in absorption efficiency, translocation rate of Nitrogen from root to shoot and assimilation of Nitrogen into organic compounds and some cultivars with superior nutritional quality (**Li *et al.*, 2022**).

The three-way interaction effect of ascorbic acid and potassium humate and cultivars was significant. The cultivar Rama and foliar application of ascorbic acid ( $150 \text{ mg L}^{-1}$ ) + potassium humate  $2 \text{ g L}^{-1}$  gave the highest values of nitrogen and protein contents. According to research, the synergic effects of humates and antioxidants are obviously achieved. The nutrition status and protein content of the combination treated plants are better than those treated with either of the component (Bulgari *et al.*, 2024). The practical significance of higher nitrogen and protein contents before storage lies in the enhancement of nutrition value and market quality of lettuce. Moreover, further enhancing the capacity of the plant to conserve its key elements during the postharvest stages involves reducing the rate of physiological deterioration and maintaining membrane stability and metabolic activity (El-Beltagi *et al.*, 2022).

**Table (13). Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf protein content of two lettuce cultivars before storage**

Effect of foliar application of ascorbic acid ( $\text{mg L}^{-1}$ )	Effect of foliar application of potassium humate ( $\text{g L}^{-1}$ )	Cultivars		Ascorbic acid $\times$ potassium humate ( $\text{g L}^{-1}$ )	Mean effect of ascorbic acid foliar application ( $\text{mg L}^{-1}$ )
		Rama	Nader		
0	0	11.79 gh	11.10 h	11.44 e	12.93 c
	2	15.14 d	13.68 ef	14.41 c	
100	0	13.64 ef	12.75 fg	13.19 d	16.18 b
	2	19.16 c	19.16 c	19.16 b	
150	0	14.43 de	13.10 f	13.77 cd	17.41 a
	2	21.70 a	20.41 b	21.06 a	
Ascorbic acid ( $\text{mg L}^{-1}$ ) $\times$ Cultivars	0	13.46 c	12.3958 d	Mean effect of potassium humate	
	100	16.40 b	15.95 b		
	150	18.07 a	16.76 b		
Potassium humate ( $\text{g L}^{-1}$ ) $\times$ Cultivar	0	13.29 c	12.31 d	12.80 b	
	2	18.67 a	17.75 b	18.21 a	
Mean effect of cultivars		15.98 a	15.03 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

The findings in tables (14) and (15) reveal that the treatment of foliar application of ascorbic acid and potassium humate were effective in maintaining nitrogen and protein contents in lettuce leaves after cold storage operation relative to control treatment. It can be assumed that these treatments are effective in reducing the loss of nutrients and maintaining physiological quality during postharvest. As stated by Roupael & Colla (2020), use of biostimulants and antioxidants can control the loss of nitrogenous compounds. Results showed that ascorbic acid concentration could enhance nitrogen and protein contents during storage. The nitrogen and protein contents were less reduced in ascorbic acid  $150 \text{ mg L}^{-1}$  than the control treatment since it has the lowest value. Ascorbic acid plays an important role as an antioxidant which reduces the oxidative stress, prevents proteins oxidation and breakdown, improves membrane stability and controls the function of enzymes during cold storage (El-Beltagi *et al.* 2022).

**Table (14).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on the percentage of leaf nitrogen content of two lettuce cultivars after storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	1.71 gh	1.48 h	1.59 d	1.84 c
	2	2.20 e	1.97 ef	2.08 c	
100	0	2.02 ef	1.88 fg	1.95 c	2.29 b
	2	2.77 c	2.50 d	2.63 b	
150	0	2.73 cd	2.53 cd	2.63 b	3.14 a
	2	3.85 a	3.45 b	3.65 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	1.95 e	1.72 f	Mean effect of potassium humate	
	100	2.39 c	2.19 d		
	150	3.29 a	2.99 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.15 c	1.96 d	2.061 b	
	2	2.94 a	2.64 b	2.791 a	
Mean effect of cultivars		2.54 a	2.30 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (15).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf protein content of two lettuce cultivars after storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	10.68 gh	9.25 h	9.96 d	11.50 c
	2	13.75 e	12.31 ef	13.03 c	
100	0	12.66 ef	11.79 fg	12.22 c	14.35 b
	2	17.31 c	15.66 d	16.48 b	
150	0	17.08 cd	15.83 cd	16.45 b	19.63 a
	2	24.06 a	21.56 b	22.81 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	12.21 e	10.78 f	Mean effect of potassium humate	
	100	14.98 c	13.72 d		
	150	20.57 a	18.69 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	13.47 c	12.29 d	12.88 b	
	2	18.37 a	16.51 b	17.44 a	
Mean effect of cultivars		15.92 a	14.40 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

It was revealed from the experiment that slow-release potassium humate through foliar application at 2 g L<sup>-1</sup> enhanced nitrogen content and protein content during storage. Humates have the ability to stabilize complex organic compounds, such as proteins, while they are being stored. Hence the stabilization. They contribute to better absorption of nutrients, regulating ionic balance of cells and activating metabolism (**Bulgari *et al.*, 2019**). In regard to the cultivars, Rama had considerably higher nitrogen and protein post-storage than Nader which indicated that there could be underlying genetic base for the ability to hold on to nitrogenous compounds, and also physiological deterioration during storage. The differences in the maintenance of postharvest quality of cultivars are similar to those of **Kader (2002)**. The three-way interaction of ascorbic acid, potassium humate, and cultivars, based on the results in the two tables, showed that the treatment combination of 150 mg L<sup>-1</sup> ascorbic acid + 2 g L<sup>-1</sup> potassium humate + cultivar Rama produced better nitrogen and protein contents after storage. The synergistic effects of antioxidants and biostimulant in enhancing nutritional stability and storability of lettuce is in parallel with current directions in postharvest management of leafy vegetables (**Rouphael and Colla, 2020**). The practical consequences of these findings are quite significant. Remaining nitrogen and protein contents after storage: is an important indicator of an enhanced nutritional value, market quality and shelf-life of lettuce. Which guarantees the requirements of sustainable production: and contemporary supply chains of fresh vegetables.

The results presented in Tables (16) and (17) indicate the spraying of ascorbic acid 150 mg L<sup>-1</sup> on the leaves of lettuce significantly increased the percentage of potassium compared to other concentrations and control before and after storage. Ascorbic acid plays a key role in protecting plant cells against damage. In fact, its potency is almost twice that of the pure plant nutrient. Additionally, the molecule prevents damage caused by reactive oxygen species. Intake improves the absorption and buildup of potassium in leaves (**Hasanuzzaman *et al.*, 2019**). The addition of ascorbic acid has been shown to induce the physiological condition of plants, which increases photosynthetic efficiency and metabolic activity; as a result, the nutrient content of lettuce leaves is also higher (**Taiz *et al.*, 2015**). The potassium humate application at 2 g L<sup>-1</sup> was similarly superior to the control after storage for the leaf potassium content. The increase is due to humates which enhance soil characteristics, nutrient availability, and stimulate root development and improved root absorption efficiency which led to direct increase in potassium build up in the leaf tissue (**Shah *et al.*, 2018**). As far as cultivars are concerned, Rama had a significantly higher leaf potassium content at storage and post-storage than Nader. We can assume this content difference was due to the genetic differences on the uptake and internal transport efficiency of nutrients, which occur frequently among cultivars of leafy vegetables, e.g., lettuce (**Rouphael and Colla, 2020**). At the storage, the potassium content was generally lower than at the beginning of the storage due to the ongoing metabolic processes and consumption of mineral ions during storage. However, the potassium content of ascorbic acid and potassium humate-containing plants was higher than control. It indicates that the loss of potassium was restrained during storage through membrane stabilization and ionic leakage minimization (**Hasanuzzaman *et al.*, 2019**). Rephrase the passage Using Different Words (from gcuf.edu.pk)

With reference to three-way interaction of ascorbic acid potassium humate and cultivars revealed that the combination of ascorbic acid at 150 mg L<sup>-1</sup> with potassium humate at 2 g L<sup>-1</sup> on Rama cultivar was significantly better than all other interactions in leaf potassium content before and after storage as presented in Tables (16) and (17). As a result of the above interaction, the enhancement of potassium accumulation during growth, and the minimization of other minerals postharvest, are important for improving lettuce leaf quality and nutritional value (**Rouphael and Colla, 2020**). These results conform with more recent findings related to minerals uptake in any vegetable by biostimulants use (**Khan and others, 2021**).

**Table (16).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf potassium content (%) of two lettuce cultivars before storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	1.51 f	1.38 f	1.45 e	2.08 c
	2	2.80 c	2.61 d	2.71 c	
100	0	2.46 d	2.24 e	2.35 d	2.81 b
	2	3.34 b	3.20 b	3.27 b	
150	0	2.90 c	2.46 d	2.68 c	3.06 a
	2	3.53 a	3.33 b	3.43 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	2.16 d	1.99 e	Mean effect of potassium humate	
	100	2.90 b	2.72 c		
	150	3.22 a	2.90 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.29 c	2.03 d	2.163 b	
	2	3.22 a	3.04 b	3.13 a	
Mean effect of cultivars		2.76 a	2.53 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

**Table (17).** Effect of foliar application of ascorbic acid and potassium humate and their interaction on leaf potassium content (%) of two lettuce cultivars after storage

Effect of foliar application of ascorbic acid (mg L <sup>-1</sup> )	Effect of foliar application of potassium humate (g L <sup>-1</sup> )	Cultivars		Ascorbic acid × potassium humate (g L <sup>-1</sup> )	Mean effect of ascorbic acid foliar application (mg L <sup>-1</sup> )
		Rama	Nader		
0	0	1.39 g	1.15 h	1.27 f	1.87 c
	2	2.63 d	2.32 e	2.47 d	
100	0	2.39 e	2.15 f	2.27 e	2.59 b
	2	3.14 b	2.67 d	2.90 b	
150	0	2.86 c	2.44 e	2.65 c	2.89 a
	2	3.33 a	2.93 c	3.13 a	
Ascorbic acid (mg L <sup>-1</sup> ) × Cultivars	0	2.01 d	1.73 e	Mean effect of potassium humate	
	100	2.76 b	2.41 c		
	150	3.10 a	2.68 b		
Potassium humate (g L <sup>-1</sup> ) × Cultivar	0	2.22 c	1.91 d	2.06 b	
	2	3.03 a	2.64 b	2.83 a	
Mean effect of cultivars		2.62 a	2.28 b		

Means that have the same letter are not significantly different at  $P \leq 0.05$ .

#### 4. Conclusion

According to study results, the physiological growth and productivity of lettuce plants improves when 150 mg L<sup>-1</sup> of ascorbic acid and 2 g L<sup>-1</sup> of potassium humate are applied. The application of this treatment enhanced the vegetative growth parameters and yield of the crop. It also improves chlorophyll content of leaves, dry matter protein and total soluble solids (T.S.S.). It also reduces weight loss during cold storage. The combination of ascorbic acid, potassium humate, and types of cultivars significantly improved photosynthetic efficiency and nutrient uptake related postharvest quality. The Rama cultivar

has superior genetic performance than the Nader cultivar concerning physiological performance and postharvest quality maintenance.

The findings show that adding biostimulants and antioxidants can help to maximize yield and market quality of leafy vegetables. The sustainable solutions presented here will help reduce losses at the postharvest stage while enhancing the nutritional quality of lettuce.

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## استراتيجيات مستدامة لتحسين النمو والإنتاجية والصفات الخزنانية باستخدام حامض الأسكوربيك وهيومات البوتاسيوم لصنفين من الخس (*Lactuca sativa* L.)

بدران سبهان اغا - مهند عقيل احمد - أنغام طلال محمود الجلبلي

قسم البستنة وهندسة الحدائق، كلية الزراعة والغابات، جامعة الموصل، الموصل، العراق

### الخلاصة

نذت هذه الدراسة في حقل الخضراوات بجامعة الموصل خلال موسم النمو ٢٠٢٤-٢٠٢٥ بهدف تقييم تأثير الرش الورقي بحامض الأسكوربيك وهيومات البوتاسيوم على النمو والإنتاجية والصفات الفسيولوجية لصنفين من الخس (Rama و Nader) شملت الدراسة على ثلاث عوامل حامض الأسكوربيك بثلاث تراكيز (٠، ١٠٠، ١٥٠ ملغم/لتر) وتركيزين لهيومات البوتاسيوم (٠ و ٢ غرام/لتر) وصنفين من الخس صممت التجربة وفق تصميم القطاعات العشوائية الكاملة بثلاث مكررات، تم قياس صفات النمو الخضري، الإنتاجية، المحتوى الكلوروفيل، المادة الجافة، البروتين، المواد الصلبة الذائبة، وفقدان الوزن قبل وبعد التخزين المبرد لمدة ٢١ يومًا. أظهرت النتائج أن الرش بحامض الأسكوربيك ١٥٠ ملغم/لتر مع هيومات البوتاسيوم ٢ غرام/لتر أدى إلى تحسين معنوي لجميع مؤشرات النمو الخضري والإنتاجية، بما في ذلك عدد الأوراق، ارتفاع النبات، وزن الرأس، والحاصل الكلي، بالإضافة إلى زيادة المحتوى الكلوروفيل، المادة الجافة، TSS، النتروجين، البروتين، والبوتاسيوم، وتقليل فقدان الوزن خلال التخزين. كما سجل الصنف Rama أفضل أداء مقارنة بالصنف Nader في جميع الصفات المدروسة. أظهرت التداخلات الثلاثية بين حامض الأسكوربيك، هيومات البوتاسيوم، والأصناف تأثيرًا تآزريًا (synergistic effect) على تحسين النمو والإنتاجية والحفاظ على جودة الأوراق بعد الحصاد. تؤكد هذه الدراسة أن تطبيق حامض الأسكوربيك وهيومات البوتاسيوم يمثل استراتيجية مستدامة وفعالة لتعزيز الأداء الفسيولوجي والإنتاجية والجودة التسويقية للمحاصيل الورقية، مع إمكانيةها في تحسين القيمة الغذائية وتقليل فقد الحصاد، مما يقدم رؤية عملية لتطبيق المنشطات الحيوية في الزراعة الحديثة.

**الكلمات المفتاحية:** حامض الأسكوربيك، هيومات البوتاسيوم، الخس، الإنتاجية، جودة ما بعد الحصاد، استراتيجية مستدامة.