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Ankita Mohapatra
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Prativa Sahu
Department of Horticulture, ICAR-Indian Institute of Water Management, Chandrasekharpur, Bhubaneswar, Odisha, India

Pradyumna Tripathy
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Nityamanjari Mishra
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Rajkumari Bhol
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Pragya Uikey
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Shrawarna Sarma
Department of Horticulture, Institute of Agriculture Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Sanhatiswarupa Khilari
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Gourav Ku Sarangi
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Corresponding Author:
Ankita Mohapatra
Department of Vegetable Science, College of Agriculture, Odisha, University of Agriculture and Technology, Bhubaneswar, Odisha, India

Influence of Growing Media and Cultivar Selection on Post-Harvest quality in Lettuce (*Lactuca sativa* L .) under Aggregate Hydroponic System

Ankita Mohapatra, Prativa Sahu, Pradyumna Tripathy, Nityamanjari Mishra, Rajkumari Bhol, Pragya Uikey, Shrawarna Sarma, Sanhatiswarupa Khilari and Gourav Ku Sarangi

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Abstract
The marketability of leafy greens is primarily limited by their rapid post-harvest senescence. Within aggregate hydroponic system different growing media and cultivars have different effects on leaf freshness and shelf-life. To determine the suitable substrate-cultivar combination for retaining longer freshness in hydroponically grown lettuce, a storage experiment was carried out to evaluate critical freshness indicators such as changes in physiological loss in weight and loss of chlorophyll content. Three lettuce cultivars: Romaine lettuce, Red Rose Lettuce and Lollo Rosso Lettuce were grown under three growing mediums (soil, cocopeat, cocopeat and perlite mixture). Weighing machine and SPAD meter were used to measure the significant physiological indicators of freshness of harvested lettuce leaves, over a 12 days storage period. Results revealed that Romaine lettuce cultivated in soil exhibited the highest post- harvest resilience, maintaining the lowest chlorophyll degradation that is around 11.19% and least physiological loss of weight i.e., around 2.36% at 12th day storage. In, contrast Red Rose lettuce cultivar grown in cocopeat based aggregate hydroponic system was found to be the most susceptible to degradation, reaching a peak chlorophyll loss of 24.4% and highest mean weight loss of 3.37%. Consequently, based on the observed rates of physiological weight loss and chlorophyll degradation, the combination of Romaine lettuce and soil-based media emerged as the most effective treatment for maintaining post- harvest quality. The research findings indicate that selecting specific variety- media combinations is essential for optimizing the shelf- life and marketability of lettuce.

Keywords: Lettuce, aggregate hydroponics, growing media, cultivar variation, post-harvest quality

1. Introduction

One of the popular salad leafy vegetables in the world, lettuce (*Lactuca sativa* L.), the "King of leafy salad vegetables", is prized for its crisp texture, culinary versatility and rich profile of bioactive compounds, such as vitamin C, polyphenols and essential minerals. But at the same time it is one of the most perishable horticultural products because as soon as the lettuce leaves are harvested they experience quick physiological and biochemical changes (Kumar and Agrawal, 2023, Peng *et al*., 2023) [11]. Physiological weight loss (PWL) and chlorophyll degradation are two important indicators of decline in freshness that have an immediate effect on the crop's marketability and nutritional value. An integrated strategy that starts long before the crop arrives at the storage facility is needed to address these post-harvest issues. The internal resilience and external longevity of lettuce during its post-harvest life may be significantly influenced by pre-harvest factors, particularly cultivar selection and growing media choice, according to new researches.

The main obstacle in lettuce preservation is its leaves high moisture content, which usually makes up 90 to 95% of its fresh weight (Atero-Calvo *et al*., 2025) [2]. The plants continue to transpire even after being detached from its water supply. Wilting, loss of turgidity and a flaccid appearance are signs of physiological weight loss. Even a 3% to 5% weight loss can make lettuce unmarketable because it loses its distinctive "crispness" (Martínez-Ispizua *et al*., 2022; Atkinson *et al*., 2013 [13, 3]. Senescence begins concurrently with the deterioration of chlorophyll. Chlorophyll is connected to the plant's antioxidant potential in addition to giving it the vivid green hue that consumers associate with freshness (Ebrahimi *et al*., 2023) [7].

Chlorosis, or yellowing of the leaves due to the breakdown of chlorophyll, is frequently accelerated by exposure to ethylene or incorrect storage temperatures. This biochemical change indicates a substantial decrease in the vegetable's phytonutrient density (Zhang *et al*., 2025) [23].

In addition to providing the plant with physical support, the growing medium is the main source of nutrients and moisture, which determines the structural integrity of the harvested leaves (Olle *et al*., 2012) [14]. The transition from conventional soil to soilless substrates in modern agriculture, such as peat moss, coconut coir, perlite, and rockwool, has shown that various media affect the morphophysiological characteristics of the leaf. The rate of transpiration after harvest can be considerably changed by these structural modifications. Higher initial levels of chlorophyll and antioxidants may be accumulated by a plant grown in a medium that offers a consistent, stress-free supply of nutrients, acting as a buffer against the oxidative stress that arises during storage (Cai *et al*., 2024) [6]. On the other hand, media that induce a small amount of water stress during the growth phase may cause the production of thicker cell walls and secondary metabolites, which could increase the lettuce's resistance to wilting (Yang *et al*., 2024, Paim *et al*., 2020) [22, 15]. Post-harvest management is made more difficult by genetic variation among lettuce cultivars, which range from Butterhead and Crisphead (Iceberg) to Romaine and Loose-leaf varieties. Every cultivar has a distinct genetic build up or potential that controls its antioxidant profile, respiration rate, and leaf morphology.

Some cultivars are naturally bred for slow-senescence characteristics, which have more stable chlorophyll-protein complexes by nature. Therefore, a key tactic for increasing shelf life and guaranteeing that the product keeps its fresh-picked quality throughout the supply chain is choosing the appropriate cultivar for a particular growing environment.

A complex physiological profile is produced by the interaction of the cultivar and the growing medium. Growers who want to reduce post-harvest losses and retailers who need a reliable, high-quality product must comprehend this synergy.

This study investigates how cultivar and growing media, two pre-harvest factors, affect lettuce's post-harvest stability. We can determine the best combinations that improve lettuce's (*Lactuca sativa* L.) durability by measuring chlorophyll retention and tracking physiological weight loss.

2. Materials and Methods

2.1. Experimental materials

The aggregate hydroponic experiment was conducted at ICAR-Indian Institute of Water Management during *Rabi*-2024. The experiment was laid out in Factorial Completely Randomized Design (FCRD) with two factors (growing media as Factor A and cultivar as Factor B) and three replications. The Chlorophyll content and lettuce leaf biomass were quantified using a SPAD-502 Chlorophyll meter and a precision balance, respectively.

2.2. Experiment method

The experiment was carried with 9 treatments that are three cultivars *viz*., Lollo Rosso (V_1), Romaine (V_2) and Red Rose (V_3) were grown in three growing medias *viz*., cocopeat + perlite (M_1), cocopeat (M_2) and soil (M_3). From each treatment and replication 5 plant samples were collected to record the observations. In accordance with established storage protocols (Guan *et al*., 2009) [10], the lettuce samples were packed in zipper polythene packets and stored in refrigerator at a temperature of 2-4ºC with 75-80% of relative humidity (RH).

2.2.1. Loss rate of chlorophyll content

Chlorophyll concentration in plant tissues is a primary indicator of the characteristic green pigmentation in leafy vegetables and serves as a reliable proxy for leaf degradation or senescence during the storage phase. To estimate the chlorophyll degradation, a SPASD- 502 chlorophyll meter was employed to monitor the changes non-destructively, preserving the sample integrity for sequential analyses. To ensure representative sampling, eight to ten points were measured, excluding 2-3 leaves from the top and bottom of the lettuce plant sample. Care was taken to maintain uniform spacing between measurement points while avoiding any physical damage to the leaf tissues. The relative chlorophyll content (C_n) was recorded as the mean of these measurements for each sampling day. To facilitate a meaningful comparison between different hydroponic cultivars with varying initial pigment densities, the analysis focused on the rate of chlorophyll loss (Eq.1) rather than absolute SPAD values.

$$\Delta C_n = (C_1 - C_n / C_n) \times 100\% \quad \text{(Eq.1)}$$

Where C_1 represents the relative content of chlorophyll in the lettuce sample on the 1st day (SPAD); C_n represents the relative content of chlorophyll on the nth day (SPAD); and ΔC_n is the degradation or loss rate of chlorophyll (%).

2.2.2. Physiological weight loss rate

The freshness of hydroponic lettuce was monitored by tracking its weight loss, which serves as a direct indicator of moisture loss during the storage. The initial weight of the samples on 3rd, 6th and 9th day of storage was measured using a precision balance. The physiological loss in weight was calculated using the equation (Eq.2)

$$\Delta W_n = (W_1 - W_n / W_n) \times 100\% \quad \text{(Eq.2)}$$

Where W_1 is weight of lettuce leaf sample on the 1st (g); W_n is weight of lettuce on nth day (g); and ΔW_n is weight loss rate of lettuce on nth day and presented in percentage (%).

2.2.3. Change in Total Soluble Solid (ºBrix)

The TSS of different lettuce cultivars under different growing medium were measured using a hand refractometer with a range of 0-32, at 3, 6, 9 and 12 days of storage. 2-3 drops of leaf extract was placed on the refractometer prism's glass and carefully cover and the TSS was compared to the light.

3. Results and Discussion

3.1. Rate of Loss of Chlorophyll Content

The change in SPAD values, used as a proxy for chlorophyll content, was monitored from 3 to 12 days after harvest (Fig.1). The reduction in SPAD values ranged from 2.15 to 4.44 units, corresponding to a percentage chlorophyll loss between 11.19% and 24.24%. Among all treatment combinations, the highest chlorophyll loss (24.24%) was observed in Red Rose cultivar grown in cocopeat based growing media, followed by Red Rose grown in cocopeat + perlite at 23.28% and Lollo Rosso in cocopeat at 23.10%. Conversely, the lowest chlorophyll loss (11.19%) was recorded in soil grown Romaine lettuce grown, indicating that soil-based cultivation was most effective in minimizing post-harvest chlorophyll degradation.

The high SPAD reductions in Lollo Rosso and Red Rose that is 4.44 and 4.40 units respectively can be correlated directly with their higher percentage of chlorophyll loss. In contrast, Lollo Rosso and Romaine grown in soil showed relatively low SPAD changes (2.15 and 2.20), aligning with their lower chlorophyll degradation. This accelerated loss in soilless media may be attributed to higher initial leaf moisture content, which leads to rapid dehydration and speeds up the senescence process. Furthermore, soilless environments support higher metabolic activity; post-harvest, leaves may continue active metabolism, producing Reactive Oxygen Species (ROS) that damage chlorophyll and cell membranes (Fagundes *et al*., 2013) [8].

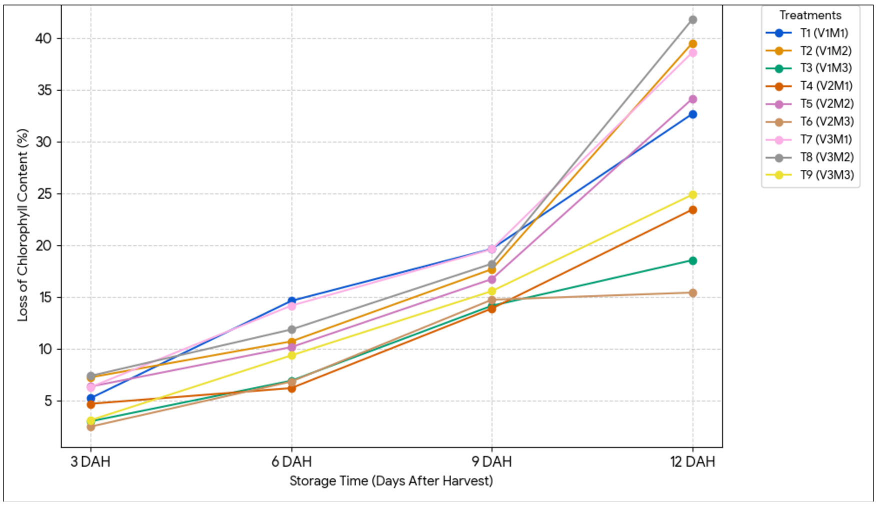

Fig 1: The rate of loss of chlorophyll content with time

3.2. Physiological Loss in Weight (PLW): The rate of weight loss of hydroponic lettuce increased with increased time. The lettuce leaf continue to transpire and respire after harvest (Volpe *et al*., 2018) [17], which mainly leads to moisture loss (Qian *et al*., 2018) [5].The physiological weight loss (%) of the lettuce was measured at 3, 6, 9, and 12 days after harvest (Fig. 2). At 3 days, Red Rose showed the highest mean loss (2.27 this may be due to higher leaf area of the cultivar as compared to other two lettuce cultivars i.e., higher leaf surface area to volume ratio which led to higher metabolism and moisture loss (Shezi *et al*., 2024) [19]. Regarding growing media, cocopeat resulted in the greatest mean weight loss (1.96%), compared to cocopeat + perlite (1.76%) and soil (1.59%). These trends persisted through day 12, where Red Rose and cocopeat consistently recorded the highest weight loss (3.73% and 2.96%, respectively).

The lower weight loss observed in soil-grown plants compared to cocopeat can be explained by plant anatomy and physiology. Research indicates that lettuce grown in cocopeat exhibits higher transpiration rates and enhanced physiological functions, such as stomatal conductance and photosynthetic rates (Sarkar *et al*., 2021; Al-Ajlouni *et al*., 2024) [18, 1]. While these attributes result in leaves that are richer in water, they also make the plants more prone to rapid water loss once detached from their hydration source (Fanourakis *et al*., 2013) [9]. Furthermore, cocopeat-grown lettuce often develops softer, thinner leaves with reduced cuticle thickness due to a lack of water stress. These thin leaves lose moisture more quickly than the thicker, more rigid leaves of soil-grown plants, a finding consistent with observations in ready-to-eat lamb's lettuce (Manzocco *et al*., 2011) [12]. The high PLW in the Red Rose cultivar (3.38% at day 9) is likely due to its larger leaf surface area, which increases the area exposed to evaporation.

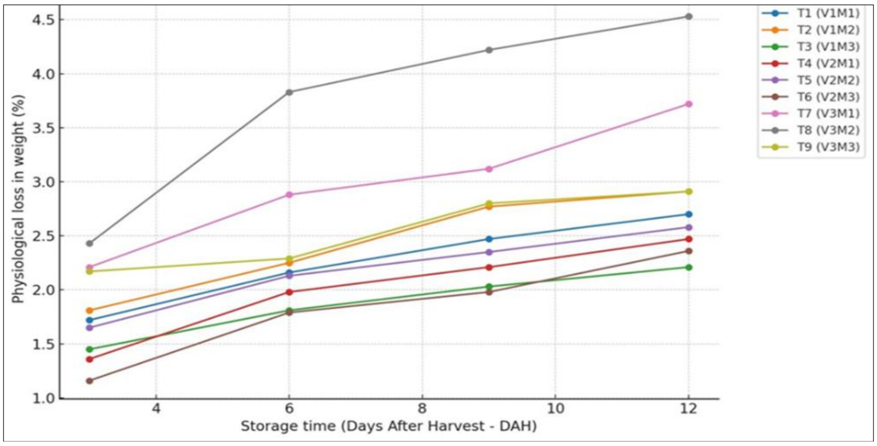

Fig 2: The rate of physiological weight loss of lettuce with time

3.3 Change in TSS value: The analysis of Total Soluble Solids (TSS) across nine treatments revealed a dynamic and non-linear pattern over the 12-day storage period. Initially, the TSS values at harvest ranged from a minimum of 4.3 °Brix in Romaine lettuce grown under soil to a maximum of 6.1 °Brix in Red Rose lettuce grown under cocopeat and perlite mix media. As storage progressed, most treatments exhibited an upward trend, reaching peak concentrations between 6 and 9 DAH. Specifically, Lollo Rosso and Red Rose lettuce cultivars grown under coccopeat + perlite media. Conversely, treatments involving Romaine lettuce cultivar consistently maintained lower TSS levels, with the lowest value of 4.0 °Brix, when the cultivar was grown under soil based growing media by the end of the study. By 12 DAH, a universal decline in TSS was observed across all experimental groups, signaling a reduction in the concentration of soluble sugars.

The observed fluctuations in TSS values are indicative of the complex physiological changes occurring during post-harvest ripening and senescence. The initial increase in TSS recorded between harvest and 9 DAH is primarily attributed to the hydrolysis of starch into soluble sugars such as glucose, fructose and sucrose (Vargas *et al*., 2017) [20]. This phase represents the peak of eating quality, where the conversion of complex polysaccharides maximizes the sweetness profile. However, the subsequent decline in TSS levels toward 12 DAH marks the onset of advanced senescence. At this stage, the rate of cellular respiration exceeds the rate of sugar formation. The produce begins to consume its own stored soluble solids as a metabolic fuel source to maintain cellular integrity, leading to a net decrease in ºBrix values (Batista-Silva *et al*., 2018; Verlinden *et al*., 2014) [4, 21].

The variation between treatments highlights the significant influence of genetic makeup (Variety), Lollo Rosso and Red Rose lettuce cultivars showed a higher capacity for sugar accumulation compared to Romaine lettuce cultivar. The growing media consisting of cocopeat and perlite mixture generally favored higher TSS retention, suggesting it may provide better conditions for sugar stability.

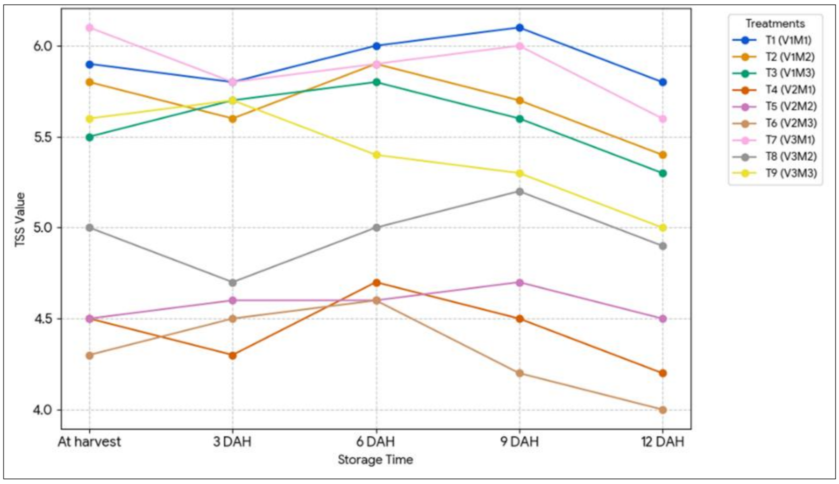

Fig 3: Change in Total Soluble Solid content of lettuce over time

4. Conclusion

In summary this experiment analysed the fresh keeping performance of different lettuce cultivars in different growing mediums under aggregate hydroponic system. High respiration rates during the advanced phases of senescence are the primary cause of post-harvest freshness decline, as demonstrated by the dynamic relationship between chlorophyll degradation, weight loss and sugar depletion. Producers should therefore give priority to cultivars that show a reduced rate of metabolic breakdown and must combine the suitable cultivar with growing medium that maintain structural integrity over the storage period in order to maintain marketable quality and nutritional value.

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