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Expert Opinion Article

Plant Extract Fortified Edible Coatings Enhanced Postharvest Shelf Life And Preserved Quality Of Mature Banana

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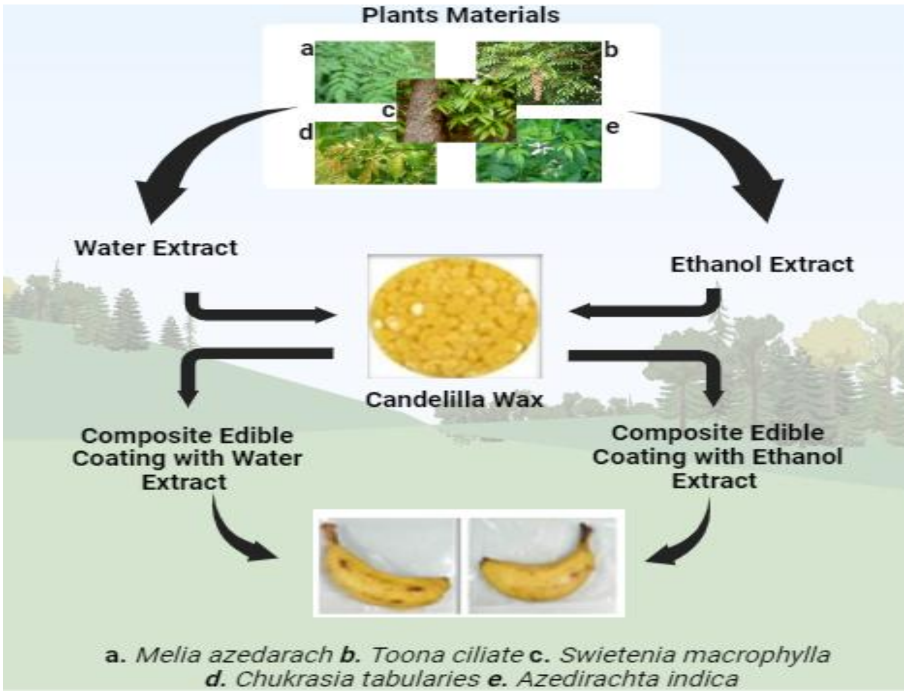
ABSTRACT
This work investigates the effects of various plant extract fortified wax/ edible coatings on the quality of mature bananas for improvement in their shelf life. The coatings under study consisted of water-based and ethanol-based plant leaf extracts of *Azedirachta indica*, *Melia azedarach*, *Chukrasia tabularies*, *Swietenia macrophylla* and *Toon ciliate* (each 4% (w/w) incorporated into Candelilla wax (16%) along with 16 % candelilla wax coatings without plants extracts. The uncoated bananas acted as a control. The coated and uncoated samples were placed separately at 22 ± 3 ºC temperature and 60-70% humidity for ten days. The assessment of quality aspects of bananas included pH, weight loss percentage, brix, firmness, color, sensory perception and physical appearance. An analysis of variance (ANOVA) test was used. It was found that all coatings delayed the ripening processes in the coated samples compared to the uncoated samples. The weight loss increased over time.

Keywords: Family *meliaceae;* Edible candelilla wax ; banana; brix; color; firmness; pH; wt. loss %.

Research Highlights

- Synthesis of plant extract fortified wax/ edible coatings using water and ethanol based leaves extract of plants belonging to family *meliaceae*.
- The efficiency of the prepared coatings to slow down the rate of biological process assess by coating on mature bananas.
- Further the prepared coatings are good to slow down the processes like weight loss (%), color change, brix, firmness, and pH, thus enhance shelf life.
- Plant extract fortified wax/ edible coatings are eco-friendly and safe for consumers and have no hazardous on food materials.

Graphical Abstract



1. INTRODUCTION

Preserving fresh fruits has gained attention recently because of its relevance to food security, post-harvest losses, and product shelf-life [1].Fruit post-harvest quality and its shelf-life are extensively investigated [2]. Banana is a horticultural product with a small shelf-life. The mechanisms of transpiration and respiration are the key factors that cause a drop in fruit excellence and post-harvest losses. Bananas still have transpiration and respiration after being harvested as living materials [3]. Respiration causes the production of heat and a reduction in food elements in the fruit, while transpiration causes loss of fruit moisture. These both activities produce post-harvest losses such as weight loss and wilting, which results in the fruit's appearance becoming less attractive and a decline in dietary value [4-5]. Bananas are a popular fruit with nutritional value and global importance. Researchers have explored creative ways to preserve bananas and prevent fruit loss from their quick decomposition after harvest. The conventional solutions are not concerned with bananas' rapid deterioration, such as weight loss, texture softening, starch-to-sugar conversion, chlorophyll degradation, and microbial growth [6].The deterioration is due to the ripening processes of fruits, which result from biochemical changes, microbial spoilage, and physiological aging [7]. Ripening occurs when fruits achieve desirable flavor, color, palatable nature, quality, and other textural properties [8]. Due to the degradation of chlorophyll, the production of other pigments like xanthophyll's and carotene increases and causes a change in the color of the fruit [9]. The loss in texture stability causes the reduction in the skin's firmness because the changes occur in pectin inside the cellulose within the fruit skin [10-12].

To delay the process of ripening and to improve the postharvest quality and storage life of fresh foods like bananas, consumable coatings have been developed [13]. Food coatings are thin coats of edible ingredients put on fruits. They protect against water loss, microbial development, and sensory loss [14]. To enhance the freshness of fresh produce, the researchers focus on antioxidants and antimicrobial bioactive additives incorporated into biopolymers for the formulation of edible coatings [15]. Antioxidants and antimicrobials may be transported through these coatings. It may help preserve food and improve consumer health [16]. Plants leaves were extracted and hybridized with Candelilla wax to form composite waxes [17]. These plant extracts are chosen for their bioactive components, such as antioxidants and antimicrobials, which inhibit banana deterioration [18].These wax compositions need to be evaluated for their effects on banana quality. Weight loss, texture, carbohydrate and sugar content, pigmentation retention, microbiological growth, and sensory properties are carefully monitored and studied [19].

Research has intensified recently to find out how to increase banana storage life and decrease postharvest losses. Multiple factors, such as physiological changes and microbial multiplication, contribute to banana breakdown. Diverse materials and methods have enhanced banana postharvest quality and shelf life [20-21]. Avocado`s coverings are effective techniques to preserve fresh vegetables [22].The modified atmosphere packaging (MAP), used for prolonging banana shelf life, alters the environment around products [23]. This slows fruit respiration and maturation, reducing ethylene production and ripening [24]. Fumigation with 1-methylcyclopropane (1-MCP) may slow the ripening process by stopping ethylene action [25]. The regulated atmospheric storage regulates gas compositions precisely [26]. This method regulates the banana's physiological processes, maintaining firmness and color.

Ascorbic acid, citric acid, and calcium ascorbate were also used to preserve banana's color, texture and reduce oxidative processes during storage [27].The heat treatment and hot water baths were used to remove pathogen 006E and postharvest quality enhancement [28]. The short exposure to high temperatures decreases microbial burdens and increases banana shelf-life [29]. Essential oils and plant extracts wrap bananas to inhibit microbial development and oxidation, increasing shelf-life. Since enzyme and microbiological growth are inhibited, cold storage is used to store bananas after harvesting.

For this reason, microorganisms, including bacteria and fungi, have been studied to fight banana postharvest illnesses. Nanotechnology has increased postharvest quality improvements. Increasing banana shelf-life by lowering microbial burdens and delaying maturity with ozone treatment is ecologically friendly [30]. The use of ionizing radiation to minimize microbiological contamination and improve banana shelf-life has been studied. Irradiation kills microbes and insects, extending storage time and minimizing degradation [31]. Effective humidity control in storage affects banana quality. Low humidity promotes moisture loss and worsens fruit texture [32]. In contrast, excessive humidity supports fungal growth. Humidity management reduces the issues and extends banana shelf-life [33].

Besides coatings, scientists have studied the application of plant extracts and essential oils to increase product quality. Antimicrobial and antioxidant characteristics of natural substances may prevent breakdown and oxidation, thus increasing shelf-life [34]. However, adoption of genetically modified (GM) products and regulations remain controversial [35]. The composite edible waxes and a retrospective analysis of previous methods show the scientific community's commitment to improving banana postharvest quality and addressing global food loss and waste [36]. Incorporating natural ingredients and cutting-edge technology in various materials and new approaches improves banana postharvest quality. Researchers are creating sustainable and cost-effective solutions to meet growing fresh produce demand using a multidisciplinary approach. It is crucial for the food supply chain to maintain security and resilience [37]. Finally, the increased demand for fresh food needs sustainable and effective postharvest quality improvement strategies [38].

Previously reported the impressive effectiveness of edible coatings derived from candelilla wax in enhancing the quality and shelf life of fresh-cut fruits [39], apples [40], avocados [41], bell peppers [42], and strawberries [43]. Emulsification plays a crucial role in manufacturing these lipid-based edible coatings by enabling the complete mixing of different ingredients and components within the system. This process ensures uniform particle size and distribution within the dispersed phase, enhancing the barrier properties against mass transfer in the resulting film.

The short shelf-life of the mature banana fruit is one of the biggest challenges to solve in Pakistan. In the current study, we formulated the plant extract fortified wax/ edible coatings. These coatings were applied to mature banana with the aim of retarding deterioration and preserving fruit quality. The findings from this study will serve as a foundation for developing optimized formulations of edible coatings to preserve the quality of banana in Pakistan. The fully mature bananas are readily available in Pakistan and have a limited shelf-life (3–5 days at 25 °C), so we chose them as the experimental subject. We assessed several physicochemical characteristics during storage, such as weight loss, pH, firmness, color, brix, physical appearance and sensory evaluation. The outcomes of this research might significantly change postharvest practices, improving fruit preservation and benefiting consumers and farmers. This is the first time five local medicinal plants belonging to the family *Meliaceae* were used to form the plant extract fortified wax/ edible coatings.

2. MATERIAL AND METHODS

2.1 Materials

Bananas of the same size, age, and color were purchased from the fruit market in Lahore. They were matured and yellow. They were washed in running water to remove dust particles. Afterward, the fruits were disinfected by dipping in a solution of NaOHCl (0.2 g/L %) for 3 min. The fruits were rinsed with distilled water thoroughly and then air dried at room temperature [44].

2.2 Preparation of water and ethanol-based plant extracts

Leaves of *Azedirachta indica*, *Melia azedarach*, *Chukrasia tabularies*, *Swietenia macrophylla* and *Toon ciliate* collected from the Lahore Botanical Garden and identified by Botanist at G. C. University Lahore. After being cleaned with water and dried in the shade, the leaves were ground into powder. Subsequently, the 10 g powder was boiled with continuous shaking for 30 min in 100 ml (10% w/v) of purified water [45]. The supernatants were poured into fresh plastic cylinders and put through a vacuum pump to be filtered. Afterward, the samples were re-filtered at lower pressure. The extract was dried in a oven at a temp of 35- 50˚C for about 8-10 hours The concentrated extracts were then kept in a refrigerator at 4°C until further usage [46].

The Soxhlet apparatus was used for ethanol-based extraction. The thimble was loaded one by one with an average of 20-25 g of leaf powder for each plant. The powder was extracted with 350 ml of ethanol at 50-58ºC temperature for 10h. The resultant crude extract was filtered using filter paper and the resulting filtrate was then subjected to a rotary evaporator. The ethanol was utterly removed from the extract. The concentrated extract is kept in a refrigerator for further use [47-49].

2.3 Preparation of composite wax coatings

To produce composites wax coatings, a mixture of 4% (w/w) water-based and ethanol-based extract of *Melia azedarach*, *Toona ciliate*, *Chukrasia tabularies*, *Azedirachta indica*, *Swietenia macrophylla* and 16% (w/w) Candelilla wax in 80% (v/v) distilled water was heated with a magnetic stirrer for 30 min to accomplish uniform emulsification. These elements were combined in an appropriate vessel. The magnetic stirring apparatus was assembled to ensure a constant and stable stirring speed. The mélange was then progressively heated to a predetermined temperature. The Candelilla wax was melted and uniformly dispersed within the aqueous phase of the emulsion utilizing a controlled heating process.

This thermal treatment facilitated the formation of a homogeneous mélange in which plant extract and Candelilla wax particles were distributed uniformly throughout the water phase. Throughout the 30-minute period of agitating and heating, the emulsion was monitored closely to ensure correct emulsification. The magnetic stirrer generated rotational movement, facilitating the fragmentation of larger wax particles and their dispersion into smaller droplets. This procedure enhanced the emulsion's stability and uniformity. After 30 min, the emulsion was visually inspected to affirm that a uniform and stable state was achieved with no visible phase separation or clustering. The emulsion was then suitable for coating applications as specified in the experimental design.

2.4 Applications of wax coating and storage

The bananas were subjected to three types of coating groups. One group consisted of five water-based plant extracts composite wax coatings *Melia azedarach* (MaCWH), *Toona ciliate* (TcCWH), *Chukrasia tabularies* (CtCWH), *Azedirachta indica* (AiCWH), and *Swietenia macrophylla* (SmCWH). Second group included five ethanol-based plant extract composite wax coatings were allocated to bananas: *Melia azedarach* (MaCWE), *Toona ciliate* (TcCWE), *Chukrasia tabularies* (CtCWE), *Azedirachta indica* (AiCWE), and *Swietenia macrophylla* (SmCWE). The third group was the candelilla wax coating (CW: 16 %). The uncoated group acted as control. The banana underwent immersion in treatment solutions for 5 s, followed by air-drying for 15 min at room temperature on a laboratory bench.

Approximately 0.45mg of each composite wax coating was used for a single banana. The bananas were placed in plastic zip lock bags of size 15.24 cm by 22.86 cm and thickness of 3 mils and stored at 22 ± 3 ºC temperature and 60-70% humidity [48]. The changes in parameters such as pH, weight loss percentage, brix, firmness, color, sensory evaluation, and physical appearance were evaluated to investigate the efficacy of composite wax edible coatings. Data were assessed using a complete randomized design with three replications [50].

2.5 pH measurement

The pH values were evaluated using a pH meter (model Hanna model – HI 8424 Origin Romania). The slurry was obtained with a mixture of banana and distillate water (1:10 w/v), stirred for 5 min, and then an electrode was used to analyze pH values [51].The pH levels of bananas were investigated for 10 days.

2.6 Weight loss measurement

At the beginning of the experiment, fruits were weighed on a digital scale (model Delta range, Switzerland).The fruits were tagged and separated at the same time. The bananas were weighed at 0, 2, 4, 6, 8, and 10 d to evaluate the loss in bananas by comparing them with uncoated bananas (control), and weight loss was calculated using equation 1.

Weight loss (%) = [(initial weight - weight at specific time of storage)/initial weight] × 100 % (1)

How much weight they lost was determined by calculating a percentage of the difference in their starting (W_i) and final (W_f) weights [52]

2.7 Brix measurement

Brix levels quantify the sugar content in fruits, providing vital information about their flavor attributes. Brix was measured using a portable refractometer (ATC, China). Bananas were homogenized using a mechanical blender with the addition of water and slurry used to determine the brix value [53].

2.8 Firmness measurement

Imada texture analyzer FRTS was used to measure the firmness of fruit flesh with and without treatment. It was determined by measuring the force required for the cylindrical probe to pierce into the surface and cover the distance of 5 mm at a rate of 1 mm/s. The samples were penetrated three times on different sides [54].

2.9 Color measurement

A color reader model CR-10 plus Konica Minolta in Japan was used to detect the color of the banana fruit's epidermis, consisting of the colors L*, a*, and b*. This was undertaken to ascertain the color of the banana. Readings were obtained from three different places on each fruit, and readings were taken randomly from three different fruits chosen randomly from each replication during each phase. Measured and recorded colors were indices L* (white-black), a* (red-green), and b* (yellow-blue) using the CIELAB scale [55].

2.10 Sensory Evaluation

On the tenth day of storage, a sensory evaluation was conducted by 20 untrained evaluators. On a standard 9-point hedonic scale (dislike extremely = 1, dislike very much = 2, dislike moderately = 3, neither like nor dislike = 5; like slightly = 6, like moderately = 7, like very much = 8, and like extremely = 9), participants were asked to rate the bananas from each treatment for taste texture and overall acceptability. The panelists received all the samples simultaneously; each was coded with a three-digit number generated randomly. A consent form was distributed at the start of the investigation, and the procedure was outlined. Each member examined three samples matching the treatments [56].

2.11Shelf-Life

A visual examination was carried out to establish the products appropriate storage conditions. In this study, the shelf life of bananas was determined by using a scale that spanned from 0 to 100%, and the results were based on the pace at which the peel changed from yellow to brown. When bananas achieved a degree of browning of more than 80%, this implied that their shelf life had ended since they were no longer fit for consumption.

2.12 Physical appearance

To assess the physical appearance of the sample fruits, the color of the samples was tested daily.

2.13Statistical Analysis

A one-way analysis of variance (ANOVA) was performed using the Origin-Lab 2022 ANOVA descriptive statistical analysis tool to determine whether or not there was a statistically significant difference between the treated and the control bananas on the same day of storage. Multiple comparisons were carried out using the Tukey Posthoc test to differentiate between the means at a significance level of ≤ 0.05.

3. RESULTS AND DISCUSSION

3.1pH measurement

The pH is an important feature that determines bananas shelf -life and quality. It indicates the alkalinity and acidity of fresh produce and impacts the fresh produce's browning reaction, microbial growth, enzymatic activity, and sensory features. Fruits usually show a regular decrease in ascorbic matter with rising temperature and storage duration. The ripening process of fruit is correlated with fast or regular losses of ascorbic content and thus causes a variation of the pH value of fruit in storage time [57-58].

The data set covers 10 days, during which the pH values of the different wax coats underwent a period of fluctuation. The first pH measurement for the "AiCWE" coating show a value of 4.8, and after 4 days, the value had slowly increased to 5.2 levels. This upward trend revealed that the surrounding environment became more alkaline (Figure 1). Similarly, the pH variations found in the various coverings display diverse patterns, suggesting that the fruit's pH levels might be influenced by chemical reactions or the activity of microorganisms. This reveals that cellulose and starch contents inside the bananas degraded slowly. As the ANOVA test was applied to the experimental data (Figure 2), wax coatings were considered the single factor against multiple responses of quality determination.

The results depicted that the coating composite material “MaCWE shows less change in pH from 4.8 to 5.48 than others. However, the change in pH was slower in the coated bananas than in the uncoated ones during the storage period. Coated with the SmCWH, pH 5.8 was recorded at the end of the storage time. The minimum pH level variation in the coated bananas, as compared to the control group, resulted from the regulated circulation of O_2 through edible wax composites coat barrier for their respiratory actions [59-60].

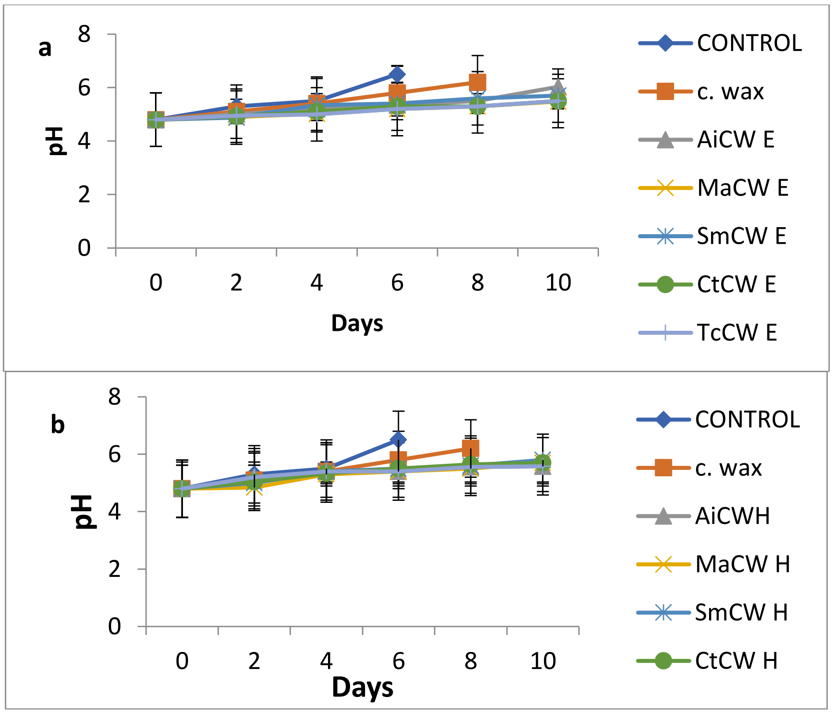


Figure 1 pH of Bananas influenced by plant extract fortified wax coatings for ten days at 22 ± 3 ºC temperature and 60-70% humidity level. (a).Represents ethanol-based plant extract fortified wax coated bananas. (b) Represent water-based plant extract fortified wax coated bananas.

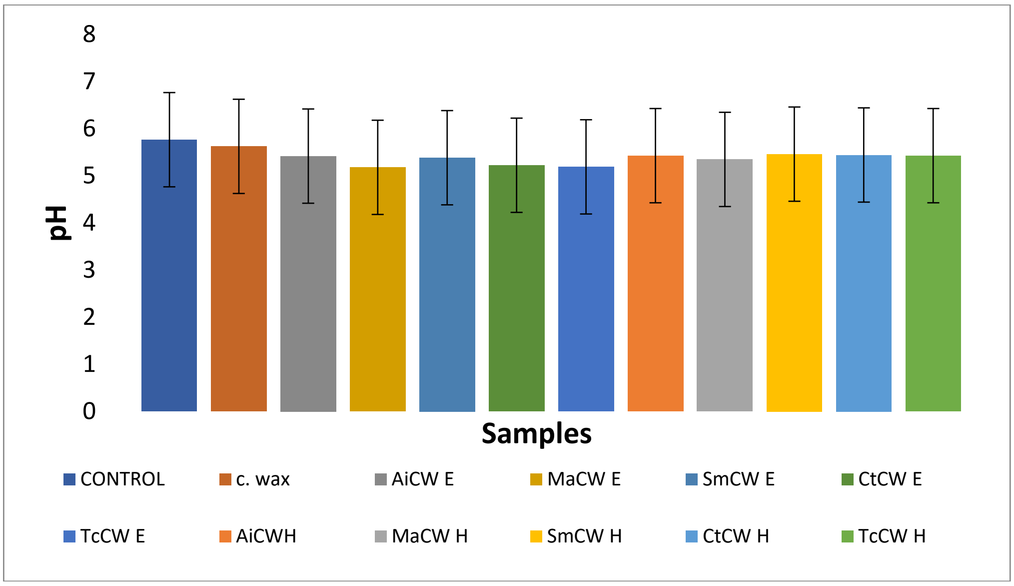
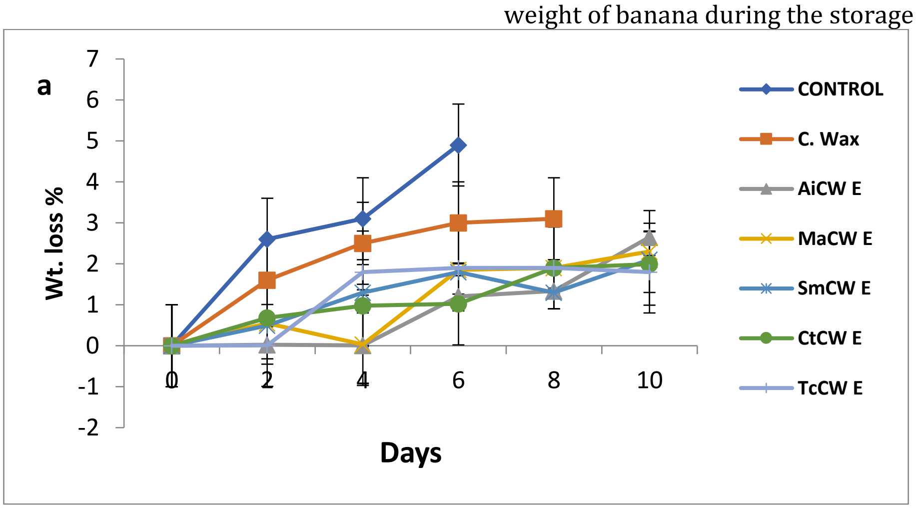


Figure 2 Comparison of pH between coated and uncoated banana represents significantly different ($p \leq 0.05$) at 95% level of confidence interval as calculated by the ANOVA test.

3.2Weight Loss measurement

Weight loss is the measurement of weight of bananas during a certain period. It occurs possibly due to processes such as evaporation, dehydration etc. The Figure 3a, showed that fruits coated with edible Candelilla wax coatings and plant extract fortified wax coatings indicated significantly lower weight loss (%) as compared to the (uncoated) control group, as the weight loss (%) gradually increased up to (8.4%) during the storage time [61]. For example, the coating labeled "AiCWE" in Figure 3a exhibited a gradual increase in fruit mass loss (2.65 %), indicating that its efficiency in retaining fruit weight might be lower than that of other coatings. The fruit coated with "MaCWH" showed a minimum weight loss of 1.09 (%). The candelilla wax coating gave 3.1% maximum weight loss reading.

All the coated samples indicated a reduction in weight loss (%) during storage time due to the impacts of plant extract fortified wax coatings and edible candelilla wax coatings, which acted as a semi-permeable barrier. This inhibited the release of CO_2, oxygen, and moisture, thus delaying the oxidation reactions, respiration, and dehydration. The weight loss was recorded at an interval of 2 d for 10 d of storage period (Figure 3a, b). From comparison between different coatings, it was found that weight loss (%) was extensively higher in the uncoated banana. Whereas the weight loss (%) of edible candelilla wax coated banana was higher than in the plant extract fortified wax coated banana ($p \leq 0.05$) as shown in Figure 4. This was due to those medicinal plants extracts enhanced the permeability of wax coating and reduced the loss in weight of banana during the storage time.



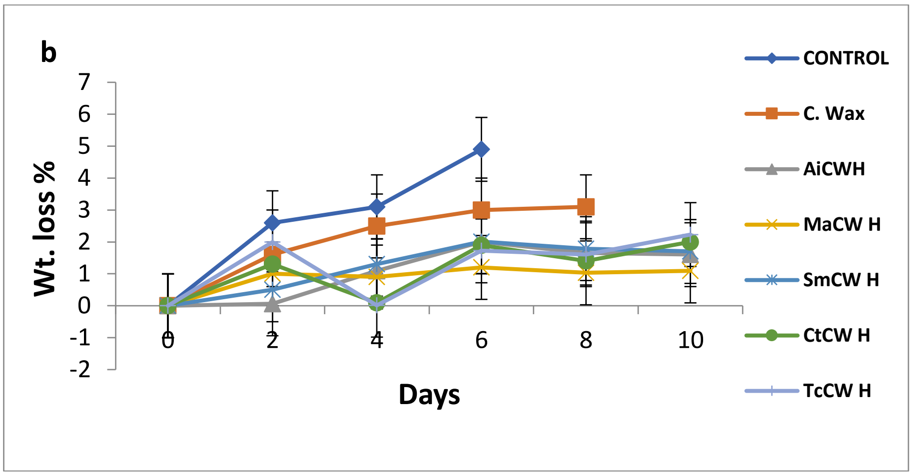


Figure 3. The effect of plant extract fortified wax coatings on weight loss (%) of bananas during storage at 22 ± 3 ºC temperature and 60-70% humidity level. (a) Effect of ethanol-based plant extract fortified wax coatings on bananas. (b) Performance of aqueous-based plant extract fortified wax coatings on bananas in storage time.

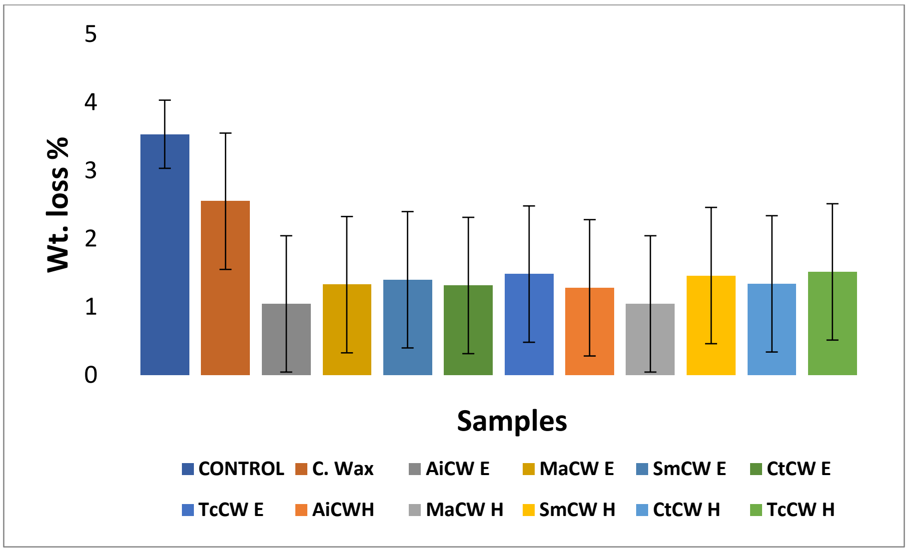
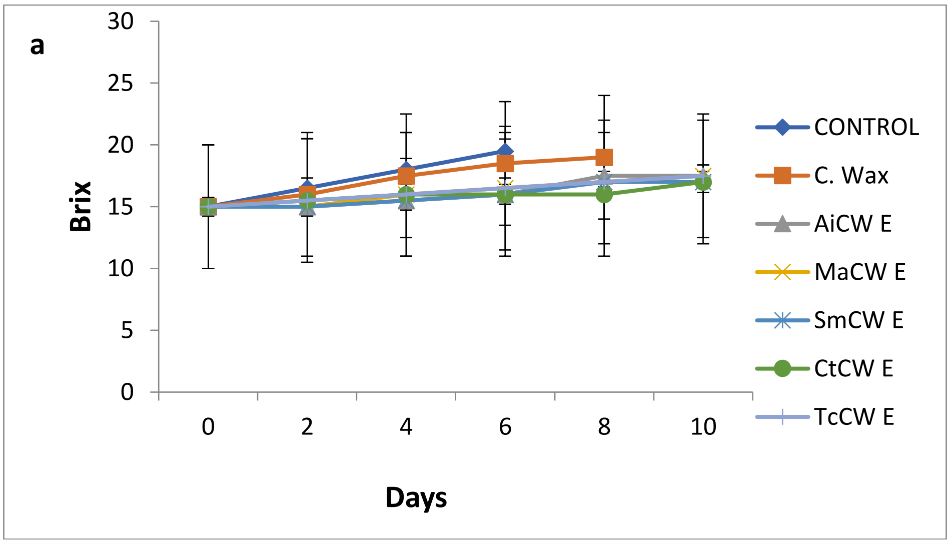
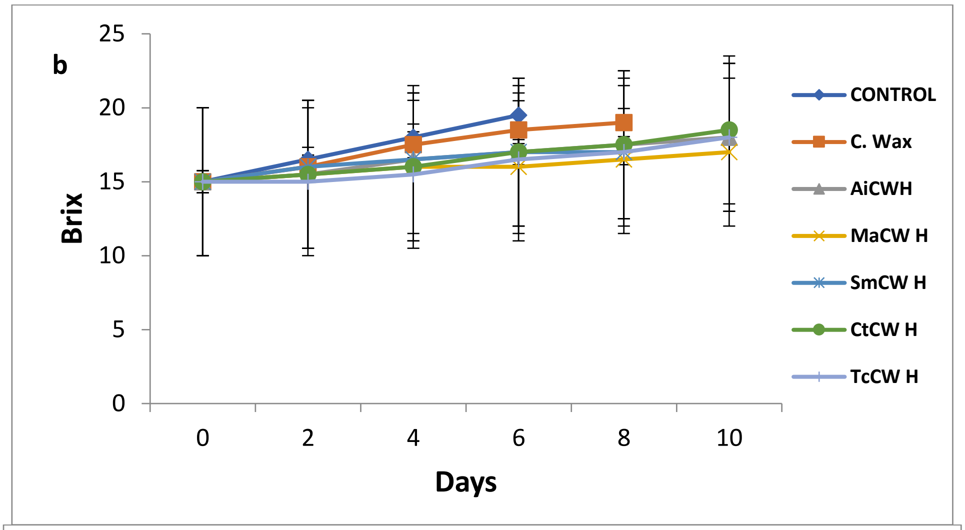


Figure4 Comparison of weight loss (%) in coated between uncoated banana represents significantly different ($p \leq 0.05$) at 95% level of confidence interval as calculated by the ANOVA test.





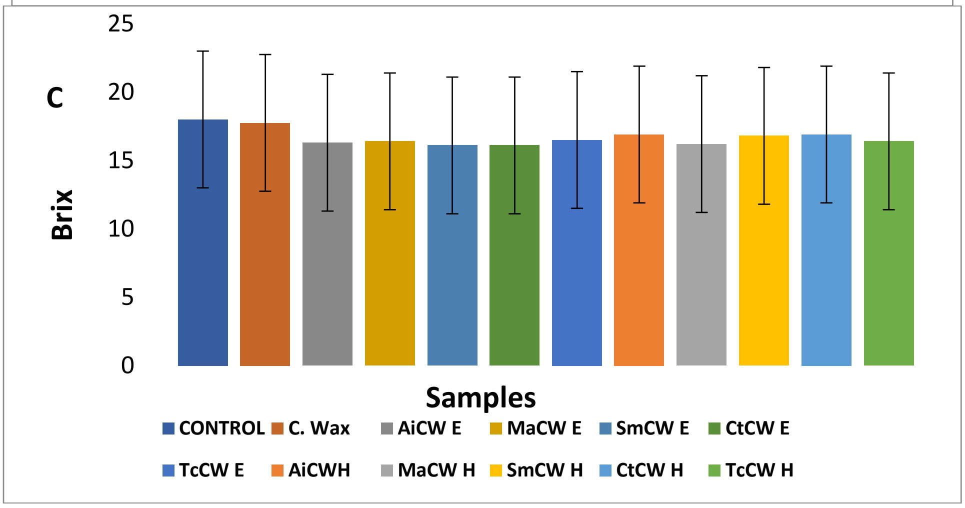


Figure 5 Brix measurement of bananas influenced by plant extract fortified wax coatings for ten days at 22 ± 3 ºC temperature and 60-70% humidity level. (a) Represents ethanol-based plant extract fortified wax coated bananas (b) represent water-based plant extract fortified wax coated bananas. (c) Comparison of brix between coated and uncoated banana represents significantly different ($p \leq 0.05$) at 95% level of confidence interval as calculated by the ANOVA test.

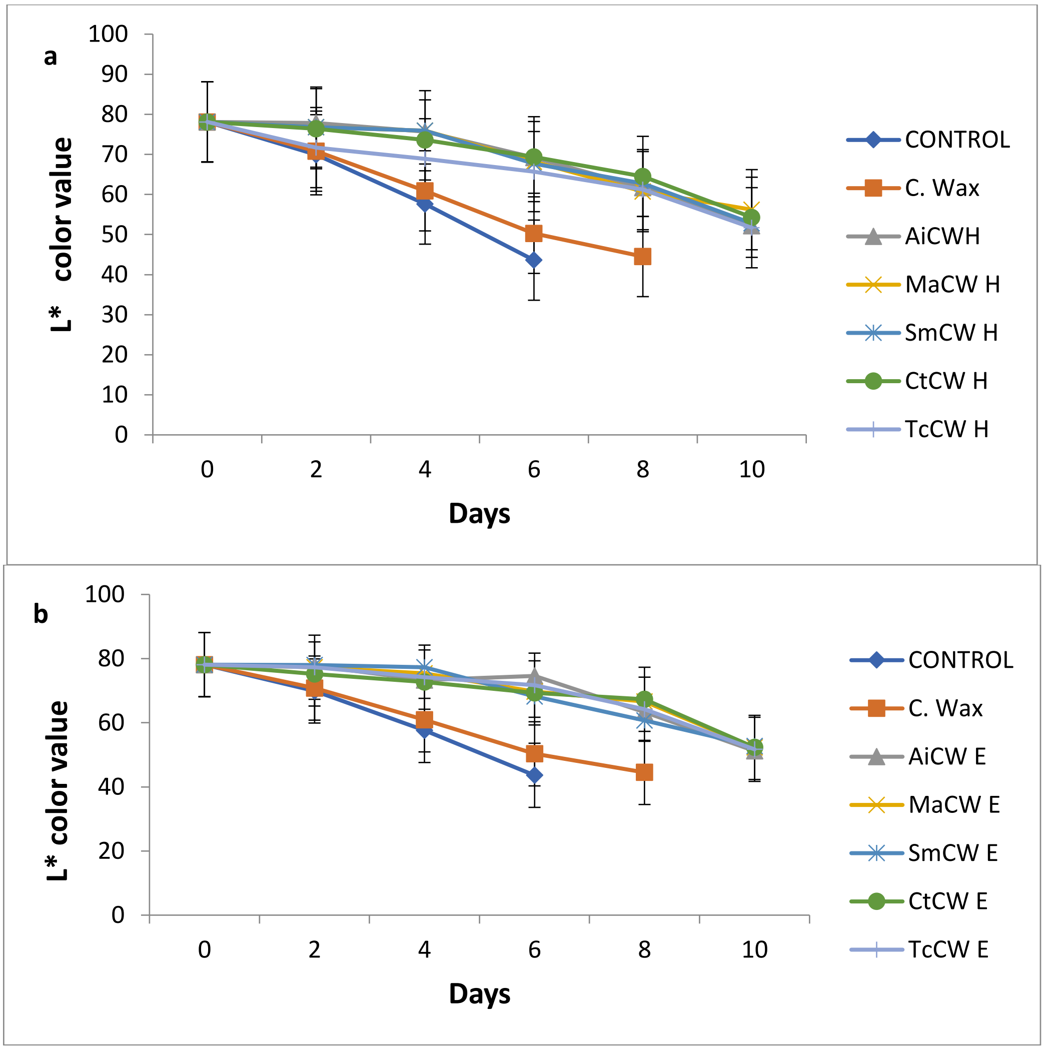
3.3 Brix measurement

Brix measurements were taken on 0, 2, 4, 6, 8, and10 days to determine the soluble solids contents of the bananas. Brix results revealed a significant pattern of dispersion, as reflected by readings ranging between15-19.5 (Figure 5) treated with plant extract fortified wax coatings, 16 % natural Candelilla wax then stored for 10 days at for ten days at 22 ± 3 ºC temperature and 60-70% humidity level. In the ripening process, the total soluble solid (Brix) increases when starch changes into sugar. A significant increase was noticed in brix during storage time Figure 5. The lowest brix was noticed for bananas coated with plant extract fortified wax coatings and candelilla wax coated as compared to the control, suggesting a better control over-ripening. The control indicated the highest brix value of 19.5, indicating more significant ripening than coated banana. Similar results were noticed when the bananas were treated with carrageenan-based coatings. The brix content of bananas usually increases as ripening progresses. In the research conducted, it was investigated that brix increased rapidly for control as compared to coated banana. [62].

3.4 Color variations

Changes in (L*) lightness, (a*) redness and greenness, and (b*) yellowness and blueness values of the plant extract fortified wax coated, 16 %candelilla wax coated and uncoated banana for ten days at 22 ± 3 ºC temperature and 60-70% humidity level as shown in (Figures 6, 7, 8). The color changes of banana peel occur due to the breakdown of chlorophyll during the ripening mechanism, so the skin color changes from green to yellow. The disintegration caused by chlorophyllase enzyme decreases chlorophyll content in fruit skin (Figure 6 a-b). The ripening process becomes slow because a layer covers the fruit's surface, affecting gas diffusion on the fruit surface [63]. The L* values for both the coated and control bananas were found to be not significantly influenced by the coating and day of storage (Figure 6 a, b, c), (p >.0.05). L* value in coated banana began at 78.1 and then slowly decreased over time. L* values showed least fluctuations in case of plant extract fortified wax coated banana.

Color analysis is an essential component in determining product quality. Figure (6a) displays color values that indicate the changes with the "SmCWE" coating show a gradual reduction. It indicates changes in the pigmentation or aesthetic qualities of the fruit during its maturity period. The color change was recorded at the rate of 2 d for 10 d of the storage period. The significant results showed a consistent effect of coatings on the sucrose content of the bananas. The changes were slower in the plant extract fortified wax coated banana as compared to candelilla wax coated bananas and uncoated banana as shown in (Figure 7 a, b, c). After 10 days, the *L** value of candelilla wax coated banana were higher as compared to others. The raise in *a** levels may be due to the change in color of the banana peels from green to dark, which is due to the decrease in chlorophyll concentration [64].The *b** values, (Figure 8 a, b ,c), (ANOVA p< 0.05) which correspond to the yellowness, increased for all samples during storage time.



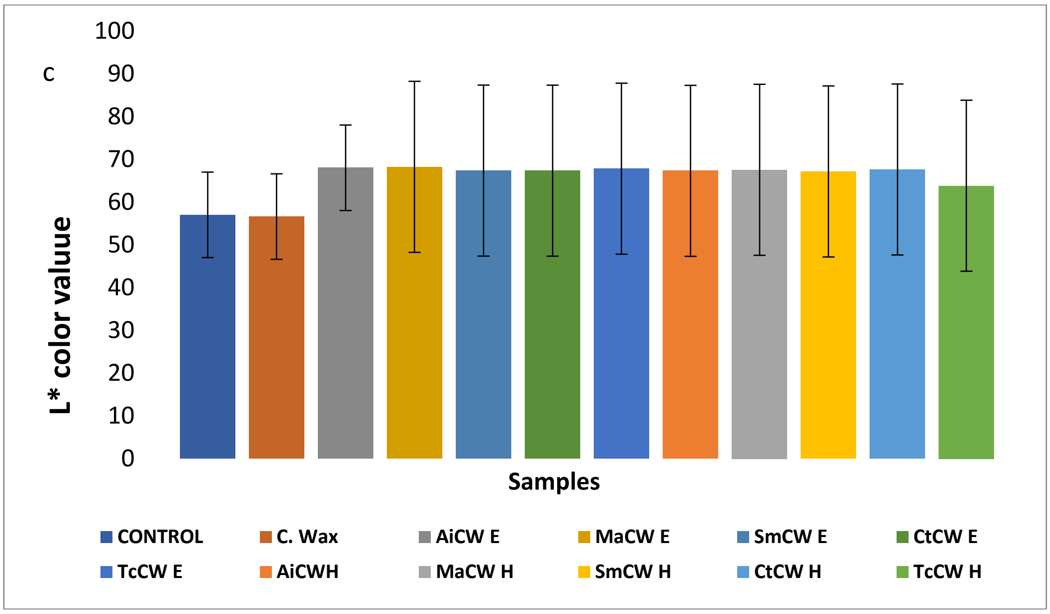
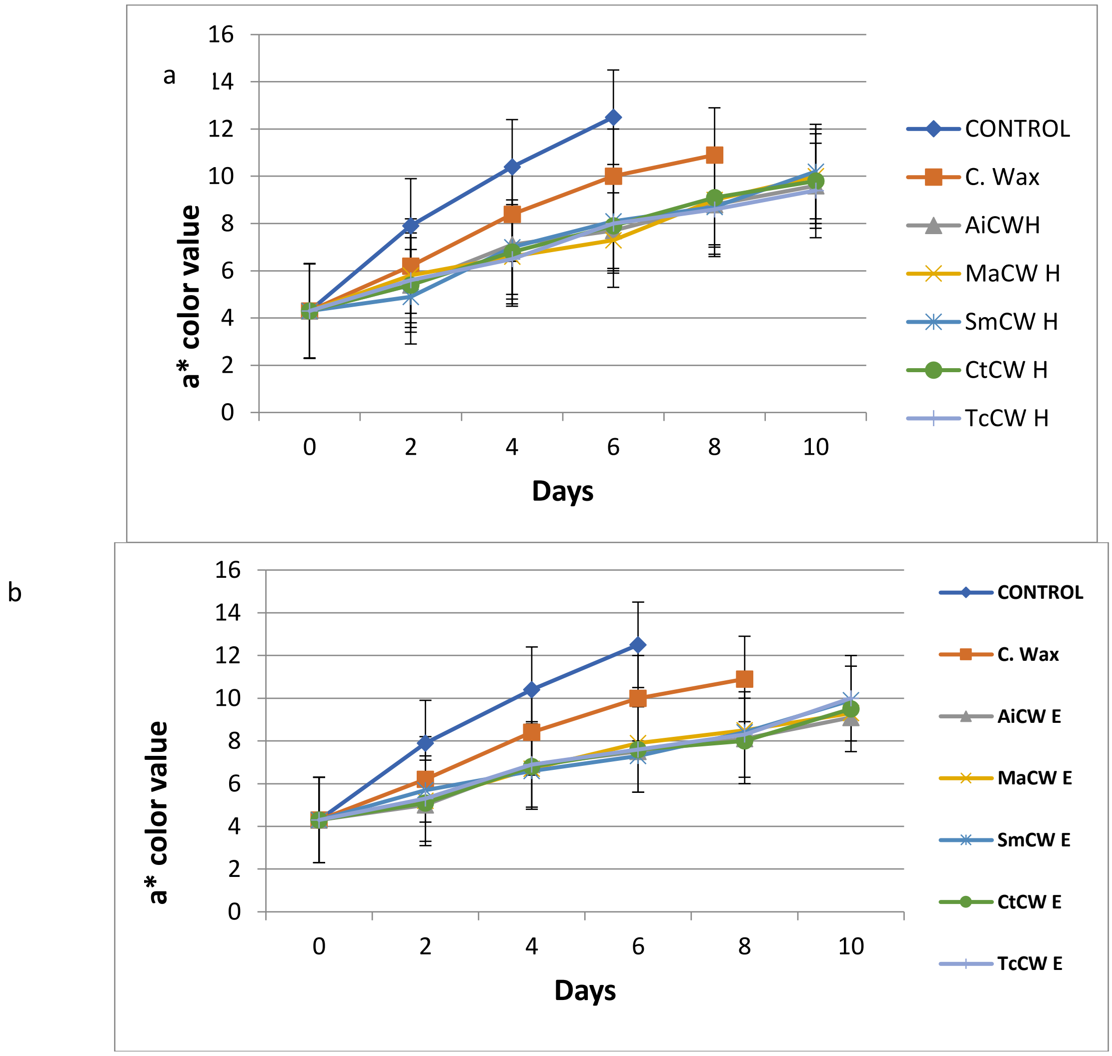


Figure 6 L* color value measurement of bananas influenced by plant extract fortified wax coatings for ten days (a) Represents ethanol-based plant extract fortified wax coated bananas (b) represent water-based plant extract fortified wax coated bananas (c) Comparisons between mean (ANOVA p >.0.05) of L* values of coated and uncoated banana for ten days at 22 ± 3 ºC temperature and 60-70% humidity level.



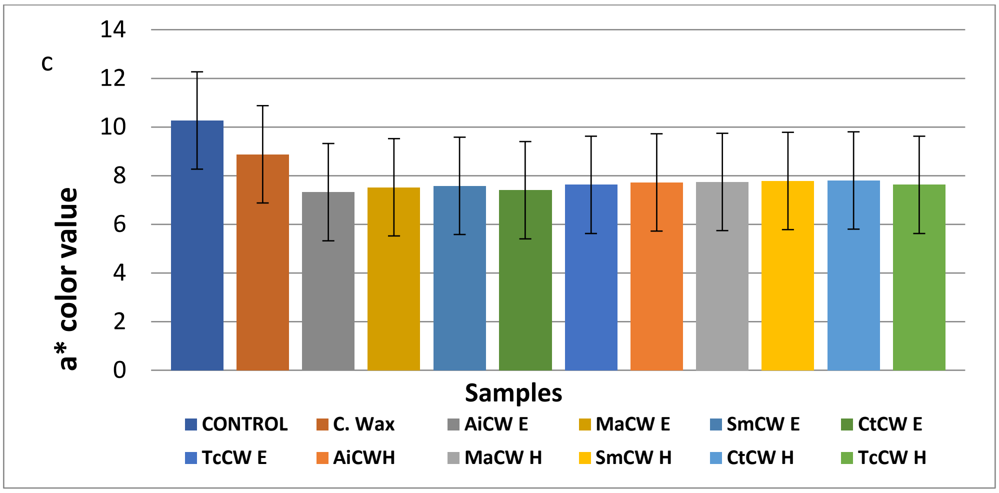
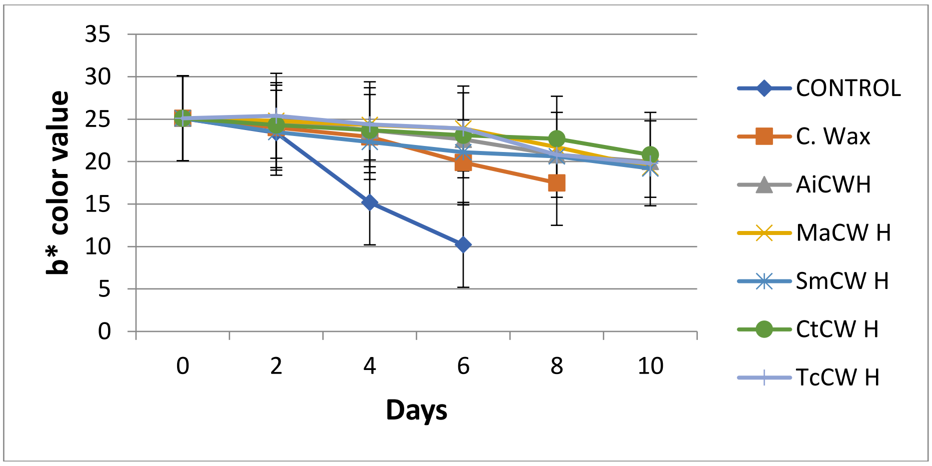
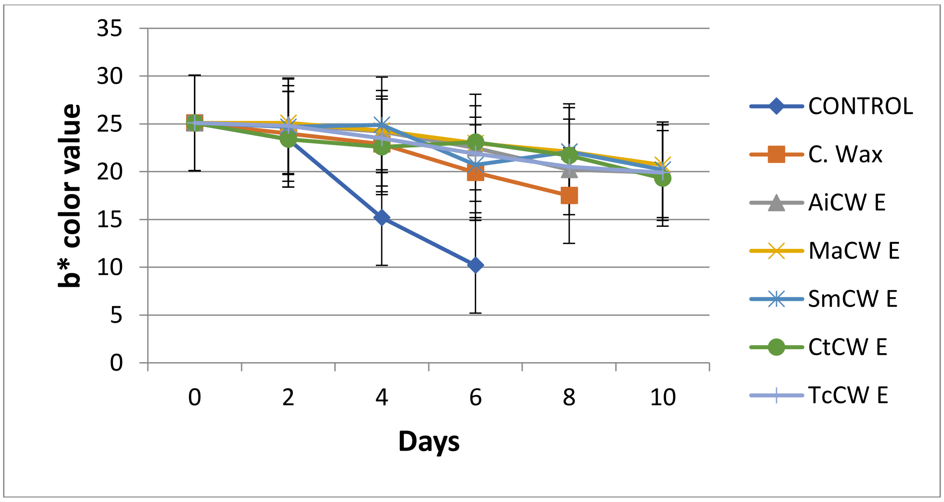


Figure 7 a* color value measurement of bananas influenced by plant extract fortified wax coatings for ten days (a) represents ethanol-based plant extract fortified wax coated bananas (b) represent water-based plant extract fortified wax coated bananas (c) Comparisons of Mean values (ANOVA, $p > 0.05$) of coated and non- coated banana during ten days at 22 ± 3 ºC temperature and 60-70% humidity level





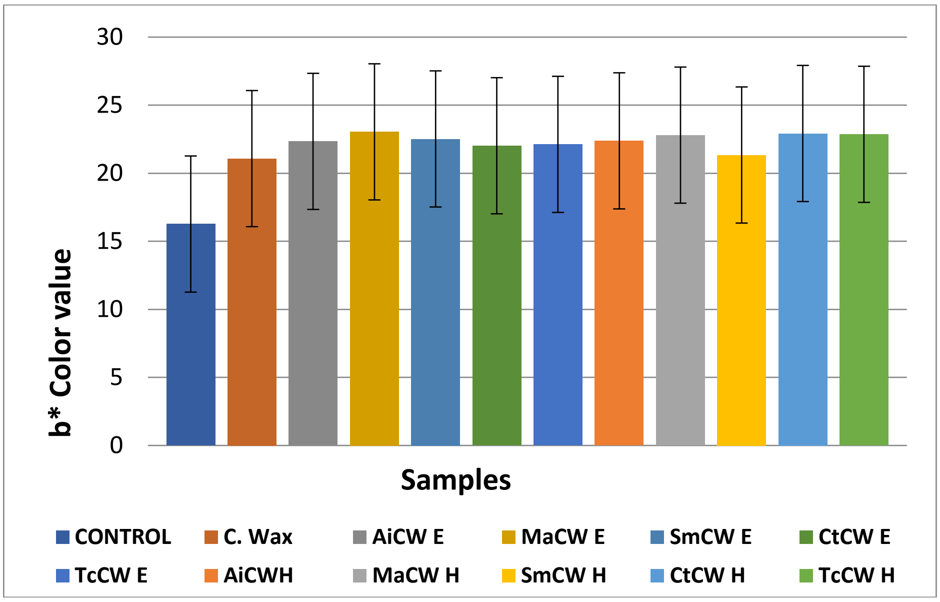


Figure 8 (a) b* color value measurement of bananas influenced by plant extract fortified wax coatings for ten days (a) represents ethanol-based plant extract fortified wax coated bananas (b) represent water-based plant extract fortified wax coated bananas (c) Comparisons of Mean values (ANOVA, $p < 0.05$) of coated and non-coated banana during ten days at 22 ± 3 ºC temperature and 60-70% humidity level

3.5 Firmness

In this research work, (significant (P <0.05) variation in physiological loss in firmness of plant extract fortified wax coated, candelilla wax coated and uncoated was observed during ten days at 22 ± 3 ºC temperature and 60-70% humidity level. Firmness is a quantitative feature that measures the fruit's capacity to endure external pressure and may be used to predict maturity and overall quality. Certain coatings, such as "MaCW E," exhibited (Figure 9a) an initial increase in firmness values followed by a continuous decrease over time. Coatings such as "SmCW H" have a greater degree of diversity (Figure 9b).

The observed variation in fruit preservation might be related to wax coatings' effectiveness in protecting the fruit's structural integrity. The storage condition and the nature of coatings material affected the ripening processes and changed the firmness values. Firmness value at the initial level (Figure 9a-b) close to 9.9 N indicates less firmness of banana fruits because of advanced maturity. After 10 days coated and uncoated groups, showed the different firmness values. The coated samples remained firm and showed maximum firmness of 6.8 N and minimum values of 4.0 N, respectively. This indicated the potential of the composite edible Candelilla wax coatings to delay the softening of fruit tissues by slowing down the ripening process as compared to the candelilla wax coated and control (uncoated) bananas.

Firmness is the main key feature that indicates the fruit quality and acceptability. The results conclude that the mature bananas coated with candelilla wax composites had the highest value of firmness, followed by Candelilla wax-coated samples (3.4 N) and the uncoated samples (2.4N) at the end of storage. TcCW coated sample gave the highest value of firmness (6.8 N). It may be due to the wax coating on the fruit exterior reducing the diffusion of water content from the surface of the fruit to the surroundings, related to the juice loss. The firmness of (**Figure 9 c**) uncoated and coated banana samples decreased significantly ($p < 0.05$) during the 10 days of storage. The enzymatic hydrolysis of the cell wall of the fruit plays an essential position in firmness of samples. This condition will enhance the cell decomposition of the bananas samples and cause a loss of firmness and changes in the structure of cell wall. Finally, the tissue of the fruit becomes soft.

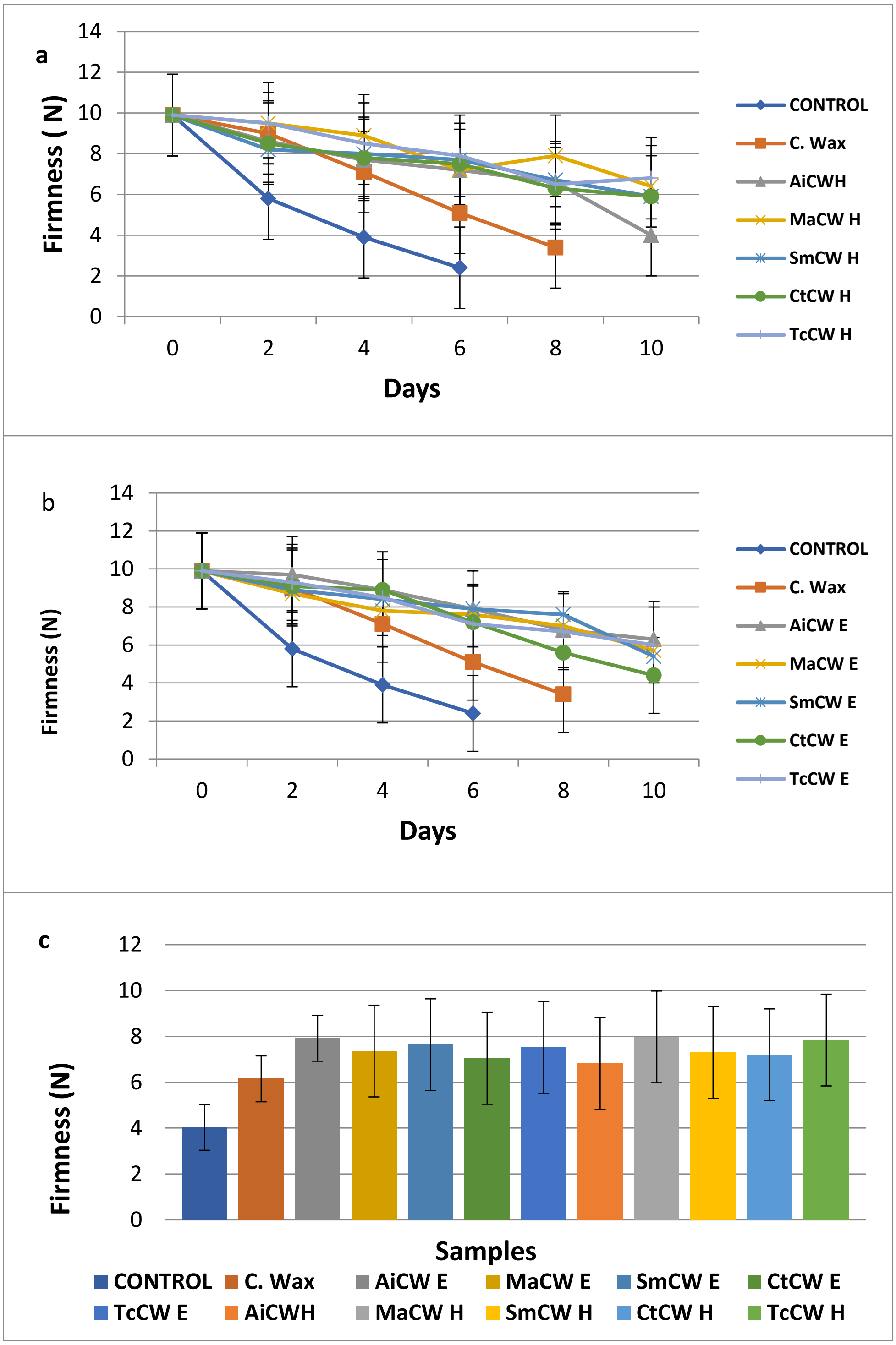


Figure: 9 Firmness measurement of bananas influenced by plant extract fortified wax coatings for ten days (a) represents ethanol-based plant extract fortified wax coated bananas (b) represent water-based plant extract fortified wax coated bananas (c) Comparisons of Mean values (ANOVA, $p < 0.05$) of coated and non- coated banana during ten days at 22 ± 3 ºC temperature and 60-70% humidity level

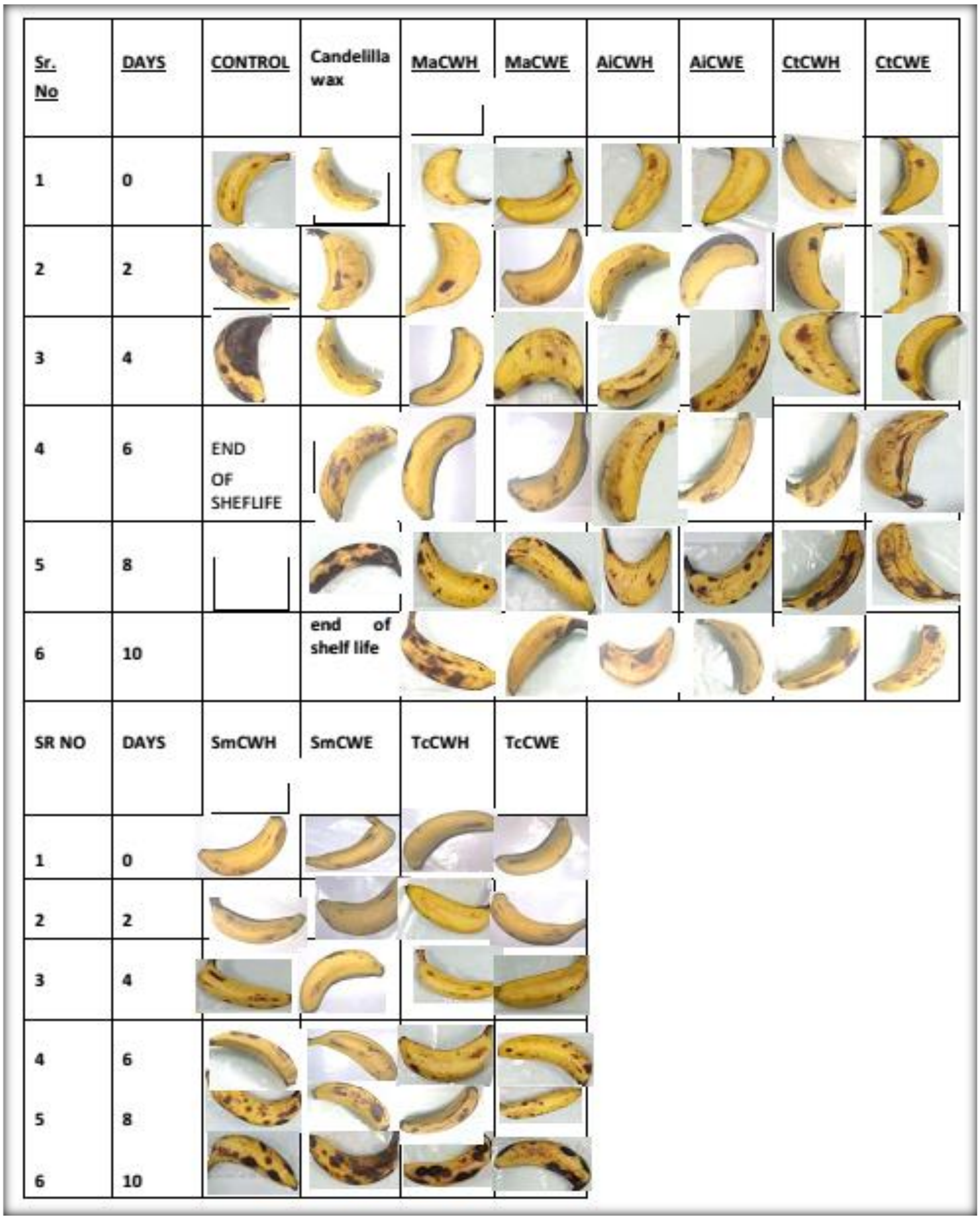


Figure 10 Physical appearance of the of coated banana (ethanol-based plant extract fortified wax coated bananas and water-based plant extract fortified wax coated bananas), candelilla wax (16%) coated banana and uncoated banana during ten days at 22 ± 3 ºC temperature and 60-70% humidity level.

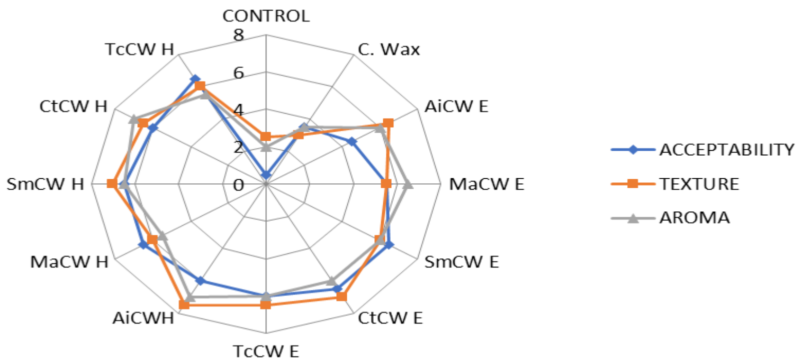


Figure 11 Sensory evaluation of coated banana (ethanol-based plant extract fortified wax coated bananas and water-based plant extract fortified wax coated bananas), candelilla wax (16%) coated banana and uncoated banana during ten days at 22 ± 3 ºC temperature and 60-70% humidity level.

Physical appearance of the coated and uncoated banana was showed in (Figures10). Banana coated with pretreatment of plant extract fortified wax coatings had the most extended shelf -life (8.9 -9.90 days), whereas candelilla wax (16%) coated banana and uncoated banana had the shelf life 7.3and 3.5 days) respectively. Sensory evaluation of the coated or uncoated samples was performed until day 10. The results of the sensory evaluation were summarized in the shape of radar plots (Figure 11). The sensory evaluation showed that plant extract fortified wax coated banana substantially showed sensory aspects better than candelilla wax (16%) coated banana and uncoated banana. This implied that plant extract fortified wax coatings could control the weight loss percentage, enhance the shelf life, and maintain Bananas' valuable attributes compared to the 16 % candelilla wax coated bananas due to the medicinal value of plant extracts belonging to the family *Meliaceae*. Overall, the plant extract fortified wax coatings are safe for consumers and the environment.

4. CONCLUSIONS

This study demonstrates the efficiency of the plant extract fortified wax coatings to maintain the banana quality for ten days at 22 ± 3 ºC temperature and 60-70% humidity level. To investigate the quality of the coated and uncoated banana certain parameters included pH, weight loss (%), brix, color, firmness, sensory evaluation and physical appearance were evaluated. Coatings materials reduced the dehydration process and control weight loss. This research work concluded that plant extract fortified wax coatings enriched with water-based and ethanol-based plant leaf extracts of *Azedirachta indica*, *Melia azedarach*, *Chukrasia tabularies*, *Swietenia macrophylla* and *Toon ciliate* were helpful for increasing the shelf -life of coated banana as compared to candelilla wax coated and uncoated banana at 22 ± 3 ºC temperature and 60-70% humidity level This was due to impact of medicinal plants extracts that enhanced the permeability efficacy of wax coating and reduced the rate of physiochemical changes of coated banana during the storage time.

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