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Calcium Chloride Efficacy on Physicochemical Properties and Microbial Count of *Chrysophyllum albidum*- Linn Fruit during Storage

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ABSTRACT

Chrysophyllum albidum fruits are underutilized because they are seasonal and perishable in nature due to physiological, biochemical and microbial alteration. This study investigated the potency of calcium chloride ($CaCl_2$) in suppressing postharvest deterioration of *Chrysophyllum albidum* fruits. Ripe wholesome fruits of *Chrysophyllum albidum* were harvested and treated with different concentrations of $CaCl_2$ (1, 2, and 3%) at three different dip times (5, 10, and 15 min). The goal was to use established analytical methods to investigate the influence of $CaCl_2$ on the firmness, weight loss, pH, titratable acidity, total sugar (TS), pectin, color, microbial (fungi and bacteria) loads of *Chrysophyllum albidum* fruits. All the treated fruits were stored at ambient temperature 28 ± 2°C and 90± 5% relative humidity for 15 days. The obtained results indicated that treating *Chrysophyllum albidum* fruits with 3% $CaCl_2$ for 15 min was found the most effective in controlling weight loss, microbial load, color, firmness, and other compositional changes such as pH, titratable acidity, pectin and total sugar. It was observed that $CaCl_2$ treated samples showed reduced fungal loads from 6.00×10^3 SFU/g at harvest to 0.02×10^3 SFU/g after 15 d of storage as compared to untreated samples. No record of bacterial load was detected on *Chrysophyllum albidum* fruits treated with 3% $CaCl_2$ for 15 min. The shelf life of *Chrysophyllum albidum* fruits could be extended for 15 d without excessive deterioration in quality by treating the fruits with 3% $CaCl_2$ for 15 min with a minimum quality loss, as compared to the control sample which had greater compositional changes with maximum quality loss during storage at ambient temperature.

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Introduction

Chrysophyllum albidum Linn. {African star apple (ASA)} is an angiosperm in the Sapotaceae family and Ebernales order (Ibrahim et al., 2017). When unripe, the fruit is dark green, but as it ripens, it turns a yellowish-orange tint, and when overripe, it turns into rusty orange color (Okoye and Ndiwe, 2016). *C. albidum* fruit has a high economic value due to its many industrial, medical, and food applications (Abolaji and Adiaha, 2015). Fruits are consumed as fresh or used to make jam, jelly, stewed fruit, marmalade, syrup, and a variety of soft drinks (Abolaji and Adiaha, 2015). *C. albidum* fruits have enormous economic potential, especially after reports that it is used to make jams and jellies that compete with raspberry jams and jellies (Arueya and Ugwu, 2017). Despite the widespread eating of this wild fruit and its significant contribution to Nigerians' nutritional intake, the palatability of fresh *C. albidum* fruits can only last a few days before it loses its aroma, color, flavor, and appearance (Iro and Ezejindu, 2017). During the ripening season of the fruit, poor storage of *C. albidum* fruits frequently results in a lot of waste (Okoye and Ndiwe, 2016). The browning in the head region (stem end) of *C. albidum* fruits could extend into the edible pulp, resulting in a loss of firmness and bursting of the fruits (Sunmonu et al., 2017). Because the fruits are frequently picked from the forest floor, they are more susceptible to microbial diseases (Arueya and Ugwu, 2017). According to studies, over 30% of *C. albidum* fruits post-harvest losses occur within five days due to high tropical temperatures and humidity, inadequate post-harvest handling practices, and a lack of proper processing and preservation techniques (Arueya and Ugwu, 2017). Despite its importance, the fruits have been mostly overlooked and underutilized due to its seasonality and perishability. The development of various cultural, physical, and chemical treatments to control post-harvest diseases has led to the development of a range of cultural, physical, and chemical therapies to control post-harvest diseases. Synthetic fungicides have proven to be an

effective treatment for a variety of infections. However, using these substances for an extended period of time can result in an increase of fungicide-resistant microbial populations. Furthermore, pesticide residues on fruits may pose a risk to consumers. As a result of these concerns, safer disease management methods have been developed (Madani and Forney, 2015). $CaCl_2$ treatment is a simple and safe method that has been known for many years to improve the post-harvest performance of many fruits and vegetables among many approved chemical compounds with low toxicity and generally recognized as safe (GRAS). $CaCl_2$ treatment might be used instead of fungicides. $CaCl_2$ has been found to help prevent crop disease by decreasing spore germination and boosting host resistance (Madani and Forney, 2015). By enhancing tissues and cell walls, $CaCl_2$ delays post-harvest ripening, inhibits the development of physiological problems, and enhances quality and post-harvest deterioration (Mujtaba et al., 2014). It has also been discovered to lower the rate of respiration, weight loss, pectin solubilization, and preserving the fruit's firmness during long-term storage (Gharezi et al., 2012). To our knowledge, the effects of post-harvest $CaCl_2$ treatments on *C. albidum* fruits quality have not been examined or given adequate consideration. This study was designed to assess the efficacy of various concentrations of $CaCl_2$ application on some physicochemical characteristics and microbial quality of *C. albidum* fruits during storage.

Material and Methods

Avondale laboratories in Banbury, Oxon, England provided the $CaCl_2$, H_2SO_4, and ascorbic acid, while Eagle Scientific Ltd. in Nottingham, NG9 6DZ, England provided the H_2O_2. HiMedia Laboratories GmbH, Einhausen, Germany provided the nutrient agar, MacConkey agar, and Potato-Dextrose agar. All of the other compounds were purchased from commercial sources (Sigma-Aldrich and Merck). All of the chemicals utilized were of the highest analytical quality. All glassware was acid cleaned and rinsed with distilled water, and the water used was glass distilled (dH_2O). The sample (*C. albidum* fruits) was assigned the voucher registration number UIH/20I6/22502 at the Botany Department, University of Ibadan, Oyo State, Nigeria, where it was recognized and authenticated.

Procurement of African Star Apple Fruits and Sample Preparation

Fresh, matured, and ripe *C. albidum* fruits were collected early in the morning from a local farm in Akure, Ondo State, Nigeria, for this study. The fruits were promptly transferred in quantity to the Federal University of Technology's Department of Food Science and Technology laboratory in Akure, Nigeria, where the research was conducted. When the fruits arrived at the laboratory, they were sorted and graded to ensure that only healthy fruits were chosen for the study. Forty healthy fruits of 2.8 kg per treatment were surface sterilized by dipping in sodium hypochlorite (500 ppm) for 10 minutes and air-dried before additional treatments to prevent microbial infection.

Treatments/Application of Chemicals

The treatment was carried out using Arthur et al. (2015)'s approach with minor adjustments. Fruits were separated into four treatment groups, each with 40 fruits, and treatments were applied according to the following protocol: T_0 = Untreated fruits served as controls, T_1 = 1% $CaCl_2$, T_2 = 2% $CaCl_2$, T_3 = 3% $CaCl_2$. The fruit of each set was dipped in 4 L treatment solution for five, ten, and fifteen minutes, respectively, for each of these treatments. The untreated samples were kept in an uncovered sterilized container lined with sterile filter paper. All treated fruits were allowed to air dry for one hour at room temperature before being stored for 15 days at ambient temperatures (28 ± 2 °C) and 90±5% relative humidity in sealed sterile high-density polyethylene (HDPE) plastic transparent containers (10 L). The samples were used in additional investigations.

Parameters Determined

Physiological Loss in Weight

Fruits were weighed before any treatment to measure the physiological weight loss. This served as the initial fruit weight. The weight loss was tracked at 7-day intervals until the final weight was reached after 15 days. The physiological loss in weight (PLW) was calculated using the formula below and expressed as a percentage of weight loss from the fruit's initial weight (Gharezi et al., 2012).

$$\text{PLW } (\%) = \frac{[(\text{IFW})-(\text{FWO})]}{\text{IFW}} \times 100 \quad (1)$$

IFW : Initial fruit weight
FWO: fruit weight on the day of observation

Fruit Firmness

The force required to make a pre-determined piercing was measured using a standard probe to determine firmness. The firmness was measured by the force registered when a standard probe was penetrated to a given depth. The firmness of the fruits was determined using a fruit penetrometer (GY-3, S/N: 9150108391) with an 8 mm plunger diameter, and the result was expressed in Newton (Arthur et al., 2015).

$$\text{Fruit firmness (N)} = \frac{\text{PR}}{\text{NR}} \times 23.8 \quad (2)$$

(where 23.8 is a constant value)
PR : Penetrometer readings
NR : Number of replicates

Total Sugar, pH, Titratable Acidity, and the Pectic Substance of the Samples

The total sugar determination in the fruit juice of *C. albidum* was analyzed using the Anthrone method, which is "a common colorimetric procedure" (Teka, 2013).

The AOAC (2000) method was used to determine the pH of the fruit samples. A clean, dry erlenmeyer flask was filled with 10 grams of the sample and 100 mL freshly distilled water. The mixture was shaken until all the particles were equally distributed and lump-free. The mixture was set aside for 10 min to allow the particles to settle. A pH meter (Jenway 3015) was used to determine the pH of the supernatant, which was decanted into a 250 mL beaker.

By titrating 5 mL of juice with 0.1 N sodium hydroxide and using phenolphthalein as an indicator, titratable acidity (reported as citric acid milligram per gram) was calculated (AOAC, 2000).

By adding $CaCl_2$ to an acid solution, pectin was precipitated as calcium pectate. After washing the calcium pectate precipitate with water until it was chloride-free, it was dried and weighed. On a fresh weight basis, the pectin content of the sample was calculated as mg/g (Geransayeh et al., 2015).

Color measurements

C. albidum fruit color was recorded using a colorimeter PCE-CSM 2 (USA) from three points at the equator region of each fruit. The color values were expressed as *L**, *a**, and *b** values. The lightness value, *L**, indicates black at 0 and white at 100. The *a** axis is relative to the green–red opponent colors, with negative values toward green and positive values toward red. The *b** axis represents the blue–yellow opponents, with negative numbers toward blue and positive toward yellow. A hue angle of 0°= red-purple, ~30° = red, ~60° = orange, 90°= yellow, 180°= bluish-green and 270°= blue. Chroma indicates the intensity or color saturation (Selcuk and Erkan, 2015). Chroma (C*), and hue angle (h^o) were expressed according to the following Equations (Yikmiş, 2019).

$$\text{Chroma, } C^* = (a^2 + b^2)^{1/2} \quad (3)$$

$$\text{Hue angle, } h^o = \tan^{-1}(b/a) \quad (4)$$

Isolation of Microorganisms/Microbial Load Determination

Media Preparation

All isolation media (MacConkey, nutrient, and potato dextrose agar) used in this study were prepared according to the manufacturer's instructions, and sterilized by autoclaving at 121°C for 15 minutes.

Microbiological Analysis of Deteriorated Fruit

Pour plate, and serial dilution procedures were used to isolate bacteria and fungi. 1 gram of the infected sections of the fruits was placed into 9 mL sterile distilled water and mixed appropriately for bacterial isolation, after which serial dilutions were performed. To count the microorganisms in each sample, 10-fold serial dilutions of each rinse water were made, and 1 ml of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} dilutions were pipetted into sterile Petri-dishes, where molten nutrient agar (NA) (45°C) was added and swirled thoroughly to ensure even distribution, and incubated at 37°C for 24 hours. Discrete colonies were counted, documented, and expressed as CFU/g (colony-forming units per gram). 1 mL aliquot dilutions of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} were dispersed on sterilized potato dextrose agar (PDA) with chloramphenicol (30 mg/L) (to prevent the growth of bacteria) on Petri plates and cultured for 7 days at ambient temperature (28 ± 2°C) for the isolation of related fungus. The fungal isolates were counted as spore-forming units per gram (SFU/g). For the total coliform count, MacConkey agar plates were inoculated for the total coliform count. On each plate, the number of colonies was counted and recorded. For each dilution, triplicate plates were made; thus, the total plate count for each dilution was calculated as the average of the three counts (Iro and Ezejindu, 2017). The microbiological analysis of healthy fruits was carried out in the same way.

Statistical Analysis

The Statistical Package for Social Sciences Software (SPSS) version 16.0 was used for statistical analysis. The standard error of the mean (S.E.) was determined for each of the three analyses. To find a treatment effect, researchers conducted one-way analysis of variance (ANOVA). All of the graphs and charts were created using Microsoft Excel 2016. Duncan's multiple range test (DMRT) was used to separate the means. At the time, the differences were deemed statistically significant $p < 0.05$.

Results and Discussion

Fruit Weight Loss

Figure 1 shows the mean percentage weight loss after ambient storage of *C. albidum* fruits. From day 7 to 15, there was a general rise in weight loss across all regimens. When compared to the control, the $CaCl_2$ treated fruits lost considerably less weight (P>0.05). Minimum weight loss was observed in 3% $CaCl_2$ (15 min), 0.49% followed by 2% $CaCl_2$ (15 min), 1.05%; 3% $CaCl_2$ (10 min), 1.20%; 3% $CaCl_2$ (5 min), 2.10%; 1% $CaCl_2$ (15 min), 2.29%; 1% $CaCl_2$ (10 min), 3.20%; 2% $CaCl_2$ (10 min), 3.34%; 2% $CaCl_2$ (5 min), 3.48% and 1% $CaCl_2$ (5 min), 4.05%, treated samples respectively at day 15 in storage. Considering the same dip duration, fruits dipped in 3% $CaCl_2$ for 15 min recorded considerably lesser weight loss than other treated fruits and the control set (Arthur et al., 2015). At days 7 and 15, there were significant variations in weight loss (P>0.05) between the three plunge times (15, 10, and 5 minutes). Fruits plunged for 15 min lost considerably less weight (P>0.05) than fruits immersed for 10 and 5 min (Figure 1). Fresh fruit loses weight mostly due to transpiration and respiration. Water was lost by transpiration as a result of changes in vapor pressure between the atmosphere and the transpiring surface (Gharezi et al., 2012). Because a carbon atom was lost from the fruit each time a carbon-dioxide molecule was formed from an ingested oxygen molecule and released into the atmosphere therefore, respiration caused weight loss (Gharezi et al., 2012). In general, the percentage weight loss in fruits treated with $CaCl_2$ was lower than that in the control group. As a result, these findings are consistent with those of Pila et al. (2010), who found that post-harvest $CaCl_2$ dipping successfully prevented weight loss in tomatoes held at room temperature. In addition, Arthur et al. (2015) discovered that $CaCl_2$ treatment reduced weight loss and resulted in a significant (P>0.05) delay in weight loss changes during storage in tomato fruit.

Fruit Firmness

All fruits in this investigation showed a general loss in firmness throughout the storage days, regardless of their dip times and concentrations. After 7 days of storage, fruits treated with 3% $CaCl_2$ for 15 minutes had significantly (P>0.05) greater values of firmness of 92.03 N than the other treated fruits and the control, as shown in Figure 2. Firmness values had decreased significantly on the final day (15 d) of storage, and the order of increasing values was observed in the fruit samples submerged in 3% $CaCl_2$ for 5, 10, and 15 min as 72.18, 73.78, and 74.58 N, respectively. The firmness of *C. albidum* fruits dipped in 1% $CaCl_2$ for 15 min, 2% $CaCl_2$, and 3% $CaCl_2$ was

considerably higher than that of fruits dipped in 1% $CaCl_2$ (5 and 10 min) and the control group. Firmness, closely related to the maturity stage, is the most essential component in fruit quality after aesthetic appearance (Gharezi et al., 2012). Most consumers like firm fruits with thin skins that do not lose too much juice when sliced (Gharezi et al., 2012). The interaction between the calcium and the pectin in the cell wall of *C. albidum* fruit may account for the increased firmness recorded by *C. albidum* fruit dipped in a higher concentration of $CaCl_2$. In addition, the variance in fruit firmness found in this study could be due to direct and indirect effects of the treatments on respiration and ripening rates. Calcium compounds have showed promising results in preserving the quality of fruits and vegetables by maintaining their firmness. Calcium makes the cell wall rigid and prevents enzymes like polygalacturonase from reaching active areas (Gharezi et al., 2012). The interaction of calcium with pectin is known to be the mechanism for the calcium firming role, according to Arthur et al. (2015). The strong interaction found between $CaCl_2$ concentration and dip time showed that the proper concentration should be applied at the right time for successful firming. The speedier weakening of their cell walls may be responsible for the general decrease in firmness in all of the samples after storage. According to Arthur et al. (2015), there was a weakening of intermediate lamellae during ripening, which could explain why the fruits softened during the ripening process. There was also a breakdown of the cell walls, a reduction in the cohesiveness of the middle lamella due to the solubilization of the pectic material, and osmosis migration of water from the skin to the flesh, all of which resulted in softening of the fruits with increasing ripening.

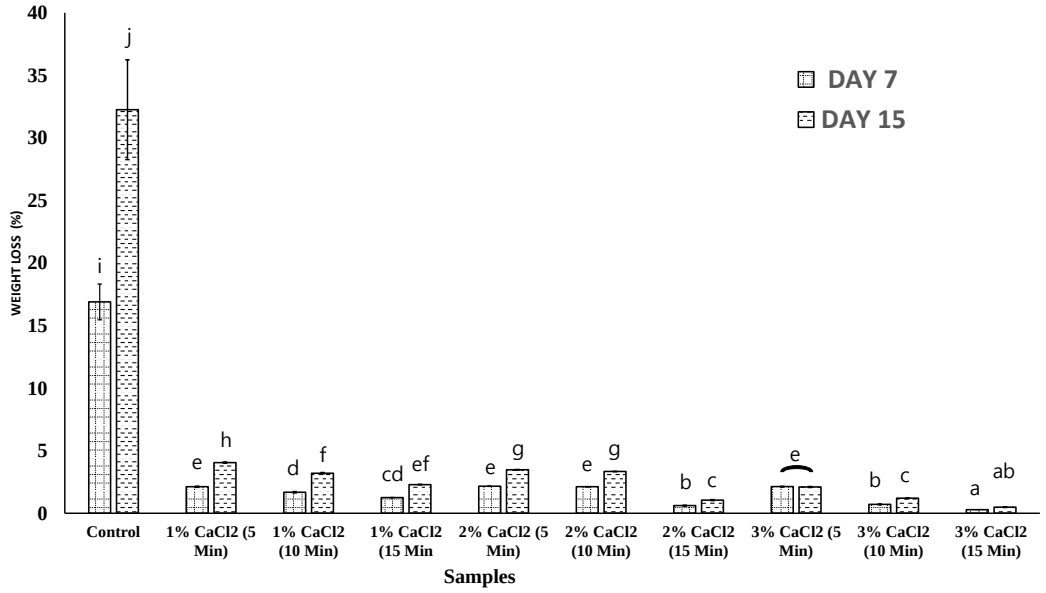

Figure 1. Effect of postharvest Calcium chloride treatment on weight loss (%) of Chrysophyllum albidum Linn. Fruit stored at 28 ± 2°C and 90 ± 5% relative humidity for 7 and 15 days. Bars represent mean ± standard error of means. Means with the same letters are not significantly different at P<0.05 using Duncan's multiple range test (DMRT).

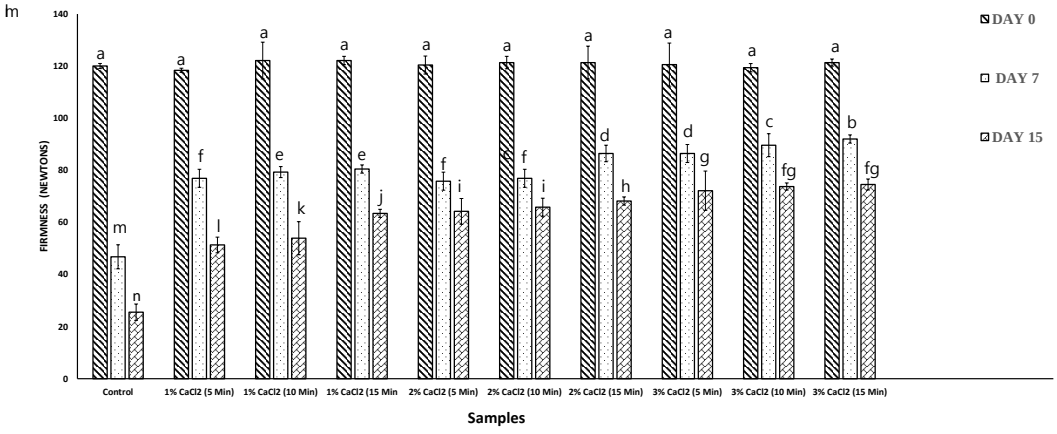

Figure 2. Effect of Postharvest Calcium chloride treatment on firmness of Chrysophyllum albidum Linn. Fruit stored at 28 ± 2°C and 90 ± 5% relative humidity for 7 and 15 days. Means with the same letters are not significantly different at P<0.05 using Duncan's multiple range test (DMRT). Bars represent mean ± standard error of means.

Calcium, being an important component of the middle lamellae, aids in the binding of polygalacturonic acid to one another, making the membrane strong and rigid. Firmness is a key sign of storage potential, and firmer fruits are known to be more resistant to physical damage during handling and transit, resulting in a longer storage life and a financial benefit. As a result, the majority of post-harvest measures are aimed at preventing excessive fruit softening (Ortiz et al., 2011). The higher the concentrations and the dip time or the exposure time the higher the firmness of the fruits samples after 15 days of storage.

Total Sugar Content

The total sugar content of the $CaCl_2$ treated fruits maintained at room temperature for 15 days showed significant differences (P>0.05). (Table 1). During storage for 15 days, the control set had a much greater mean total sugar level (609.76 mg/g) than all other treatments, followed by 2% $CaCl_2$ (10 min) (265.71 mg/g) and 3% $CaCl_2$ (15 min) treatments, which had the lowest total sugar content (197.83 mg/g). All the $CaCl_2$ treated fruits had lower total sugar content than freshly harvested fruits, while the sugar content of the control fruits rose dramatically. The rise in total sugar in the control sample could have been caused by a rapid increase in the rate of conversion of starch into sugars or the breakdown of polysaccharides into water soluble sugar. The findings of this study are consistent with those of Pila et al. (2010), who observed that $CaCl_2$ treated fruits have a lower total sugar content than the control fruits (Table 1). The reduced total sugars content seen in this study could be due to a reduction in metabolic process and a slowing down of respiration in the treated fruits. Slower respiration decreases metabolite synthesis and utilization, resulting in lower total sugar due to the slower conversion of carbohydrates to sugars (Gharezi et al., 2012).

pH

The pH is an important metric for determining the amount of free acid in a product, as it indicates the rate at which organic acids degrade into sugar (Mujtaba et al., 2014). The control samples had the highest pH value (4.30), but the pH of the treated fruits ranged from 3.29 to 3.65. (Table 1). The high pH reported (3.69) during harvest is due to the low titratable acidity (citric acid) of the freshly harvested ASA fruits (47.13mg/g). This is in keeping with Dauda's report (2014). All the treatments were found to maintain the pH throughout the storage interval with a gradual decrease in pH at the end of storage. The pH of the control samples was greater than the pH of the newly harvested fruit at day zero and the treated fruits (Table 1). This suggests that $CaCl_2$ treatment retards the ripening of the treated fruits (Mujtaba et al., 2014). The pH levels were within the range of acidic foods. The rise in acidity is related to increased activity of citric acid glyoxylate during ripening, while the fall in acidity (control) is linked to their conversion into sugars and continued use in the metabolic process during storage (Pila et al., 2010). Acidity adds to both taste and food safety by preventing microorganisms from spoiling food. The importance of food pH in the acidic range cannot be overstated. Asare et al. (2015) found that a low pH inhibited the growth of unwanted microorganisms in fruits, which could help preserve them. These findings support Souza et al. (1999), who found that applying $CaCl_2$ to strawberry fruits after harvest lowered the pH of the fruits throughout storage period, which might be due to the differences in atmosphere created by different treatments (Mujtaba et al., 2014). The findings of this study are consistent with those of Diaz-Sobac et al. (1996) and Pila et al. (2010), who found the similar pattern of results in mango and tomato samples, respectively. The pH of the chemically treated fruit, in comparison, was found to be lower than that of the control set, which could be attributed to the differences in atmosphere created by different treatments (Mujtaba et al., 2014).

Titratable Acidity

The concentration of organic acids present in the fruit as free acid, anion, or mixed as salt is directly related to total titratable acidity (TTA), which is often associated to ripeness (Mujtaba et al., 2014). During storage, titratable acidity increased significantly in all of the treated fruit samples (Table 1). As ripening continued, all of the treated fruits had higher TTA values than the control set. The TTA values in treated samples varied from 47.20 to 52.45 mg/g, while the control group had the lowest TTA value of 28.35 mg/g (Table 1). This could be attributed to the $CaCl_2$ treated fruits taking longer to fully ripen, as there are more organic acids in unripe fruit (Sting and Rouseff, 1986). When compared to newly harvested fruits (47.13mg/g) at day zero, the TTA in the control sample decreased during the post-harvest storage period. This could be due to the fact that organic acids are respiratory substrates and the fruit is transpiring at this time by increasing metabolic processes and, thus, the respiratory rate (Wills et al., 2007). These findings corroborate Madani and Forney's (2015) findings that pears sprayed with calcium in the summer and fall produced less ethylene, had reduced respiration, contained more organic acids, and were firmer after storage. The results (control) are consistent with Sartaj et al. (2013), who claimed that organic acids may be utilized in the respiration process and metabolic changes associated with ripening, resulting in a drop in final contents after storage.

Pectic Substance

The amount of pectic material found in this investigation varied a lot. Fruit samples treated with 1% $CaCl_2$ (5, 10 and 15 minutes) and 2% $CaCl_2$ (5 and 10 minutes) had lower pectic material content, whereas fruits samples treated with 2% $CaCl_2$ (15 minutes) and 3% $CaCl_2$ had higher pectic substance content (Table 1). The pectic ingredient of the treated fruits has a higher value when the salt concentrations and dip times are higher. The fruit treated with 3% $CaCl_2$ for 15 minutes had the highest value (176.97 mg/g), while the control had the lowest value (50.58 mg/g). Pectins are a heterogeneous collection of polysaccharides that contain both acid and neutral sugars, such as galacturonic acid and rhamnose, galactose, and arabinose (Santos et al., 2020). Pectins are huge, complex molecules that are responsible for the physical structure that gives fruits and vegetables their mechanical resistance (Santos et al., 2020). Calcium ions are involved in maintaining the textural quality of produce because they form cross-links or bridges between free carboxyl groups of pectin chains, resulting in cell wall strengthening (Garcia et al., 1996). The higher pectic substance observed in the treated fruits could be due to the $CaCl_2$ salts treatment delaying natural physiological processes such as respiration, ripening, and senescence, which are responsible for the solubilization and depolymerization of pectic substances and other cell wall polymers (Hussain et al., 2012).

Table 1. Postharvest response of physicochemical properties of *C. albidum* fruit to different concentrations of Calcium chloride ($CaCl_2$) treatments during storage at 28 ± 2°C and 90±5% Relative humidity for 15 Days.

Treatments	Storage (Days)	Total Sugar (mg/g)	Total Titratable Acidity (mg/g)	pH	Pectic Substances (mg/g)
At harvest	0	305.47 ± 3.53^{f}	47.13 ± 0.47^{b}	3.69 ± 0.02^{f}	104.67 ± 0.23^{g}
Control	15	609.76 ± 2.14^{g}	28.35 ± 0.13^{a}	4.30 ± 0.10^{g}	50.58 ± 5.56^{a}
1% $CaCl_2$ (5 Min)	15	204.22 ± 0.11^{b}	52.45 ± 0.03^{g}	3.29 ± 0.00^{a}	66.77 ± 0.15^{b}
1% $CaCl_2$ (10 Min)	15	225.89 ± 4.36^{d}	52.34 ± 0.08^{g}	3.27 ± 0.02^{a}	70.40 ± 0.76^{c}
1% $CaCl_2$ (15 Min)	15	204.64 ± 0.01^{b}	49.25 ± 0.03^{d}	3.55 ± 0.00^{c}	81.92 ± 0.35^{d}
2% $CaCl_2$ (5 Min)	15	215.83 ± 0.01^{c}	50.15 ± 0.03^{f}	3.47 ± 0.01^{b}	93.30 ± 0.04^{e}
2% $CaCl_2$ (10 Min)	15	265.71 ± 0.32^{e}	49.95 ± 0.03^{ef}	3.54 ± 0.01^{c}	100.25 ± 0.13^{f}
2% $CaCl_2$ (15 Min)	15	213.81 ± 0.08^{c}	49.65 ± 0.03^{e}	3.55 ± 0.00^{c}	117.77 ± 0.58^{i}
3% $CaCl_2$ (5 Min)	15	212.32 ± 0.22^{c}	49.10 ± 0.00^{d}	3.59 ± 0.00^{d}	114.27 ± 0.22^{h}
3% $CaCl_2$ (10 Min)	15	224.50 ± 0.02^{d}	48.85 ± 0.03^{c}	3.61 ± 0.00^{d}	166.37 ± 0.35^{j}
3% $CaCl_2$ (15 Min)	15	197.83 ± 0.02^{a}	47.20 ± 0.00^{b}	3.65 ± 0.00^{e}	176.97 ± 0.16^{k}

Means with the same letters within a column are not significantly different at $P < 0.05$ using DMRT. Each value is the mean for three replicates.

Table 2. Effect of postharvest calcium chloride ($CaCl_2$) on the peel color of *Chrysophyllum albidum* Linn. Fruit stored at 28 ± 2°C and 90±5% relative humidity for 15 days.

Treatment	DAT	Color coordinates				
		*L**	*a**	*b**	*C**	*h°*
At harvest	0	63.83 ± 0.02^{q}	21.19 ± 0.00^{e}	45.79 ± 0.01^{k}	50.46 ± 0.01^{l}	65.17 ± 0.00^{k}
Control	7	54.39 ± 0.04^{l}	23.74 ± 0.03^{g}	39.82 ± 0.06^{h}	46.42 ± 0.02^{j}	59.21 ± 0.03^{g}
1% $CaCl_2$ (5min)	7	58.44 ± 0.02^{n}	22.01 ± 0.01^{f}	40.70 ± 0.02^{i}	46.26 ± 0.02^{j}	61.60 ± 0.01^{h}
1% $CaCl_2$ (10min)	7	53.85 ± 0.05^{k}	24.33 ± 0.01^{h}	39.56 ± 0.06^{h}	46.45 ± 0.06^{j}	58.41 ± 0.03^{f}
1% $CaCl_2$ (15min)	7	58.92 ± 0.01^{n}	25.96 ± 0.01^{j}	45.35 ± 0.01^{k}	52.25 ± 0.01^{m}	60.21 ± 0.00^{h}
2% CaCl2 (5min)	7	62.19 ± 0.02^{p}	22.99 ± 0.02^{f}	46.26 ± 0.04^{l}	51.66 ± 0.04^{l}	63.58 ± 0.01^{j}
2% $CaCl_2$ (10min)	7	40.23 ± 0.02^{d}	18.03 ± 0.00^{c}	18.38 ± 0.00^{b}	25.75 ± 0.01^{c}	45.54 ± 0.01^{a}
2% $CaCl_2$ (15min)	7	61.08 ± 0.01^{o}	22.17 ± 0.01^{f}	43.53 ± 0.00^{j}	48.85 ± 0.01^{k}	63.00 ± 0.01^{i}
3% $CaCl_2$ (5min)	7	58.10 ± 0.05^{n}	24.22 ± 0.02^{h}	45.61 ± 0.02^{k}	51.64 ± 0.02^{l}	62.03 ± 0.02^{i}
3% $CaCl_2$ (10min)	7	57.62 ± 0.01^{m}	26.14 ± 0.01^{i}	43.76 ± 0.00^{j}	50.97 ± 0.00^{l}	59.15 ± 0.01^{g}
3% $CaCl_2$ (15min)	7	56.54 ± 0.03^{m}	24.22 ± 0.00^{h}	41.97 ± 0.00^{i}	48.46 ± 0.01^{k}	60.01 ± 0.00^{h}
Control	15	35.49 ± 0.01^{a}	15.10 ± 0.00^{a}	15.59 ± 0.00^{a}	21.70 ± 0.00^{a}	45.91 ± 0.01^{a}
1% $CaCl_2$ (5min)	15	51.12 ± 0.04^{i}	23.46 ± 0.00^{g}	38.64 ± 0.01^{h}	45.20 ± 0.01^{j}	58.73 ± 0.00^{f}
1% $CaCl_2$ (10min)	15	38.56 ± 0.03^{b}	15.53 ± 0.00^{a}	19.82 ± 0.01^{c}	25.18 ± 0.01^{c}	51.92 ± 0.01^{c}
1% $CaCl_2$ (15min)	15	42.33 ± 0.01^{e}	15.09 ± 0.01^{a}	22.70 ± 0.02^{d}	27.23 ± 0.01^{d}	56.38 ± 0.01^{d}
2% $CaCl_2$ (5min)	15	43.04 ± 0.04^{f}	18.59 ± 0.05^{c}	23.22 ± 0.06^{d}	29.75 ± 0.07^{e}	51.31 ± 0.01^{c}
2% $CaCl_2$ (10min)	15	46.70 ± 0.01^{h}	25.20 ± 0.00^{i}	30.84 ± 0.00^{e}	39.82 ± 0.01^{g}	50.75 ± 0.00^{c}
2% $CaCl_2$ (15min)	15	39.22 ± 0.00^{c}	16.17 ± 0.00^{b}	17.67 ± 0.01^{b}	23.96 ± 0.01^{b}	47.54 ± 0.01^{b}
3% $CaCl_2$ (5min)	15	45.74 ± 0.16^{g}	19.36 ± 0.01^{d}	31.77 ± 0.01^{e}	37.20 ± 0.01^{f}	58.69 ± 0.05^{f}
3% $CaCl_2$ (10min)	15	50.50 ± 0.01^{i}	21.47 ± 0.00^{e}	34.98 ± 0.20^{f}	41.21 ± 0.01^{h}	58.60 ± 0.01^{f}
3% $CaCl_2$ (15min)	15	52.10 ± 0.04^{j}	23.47 ± 0.02^{g}	37.19 ± 0.01^{g}	43.98 ± 0.02^{i}	$57.75 \quad 0.01^{e}$

DAT: Days after Treatment, The data shown are the mean ± standard error of three replicates. Statistically significant ($p < 0.05$) values within the columns are designated by different letters.

Table 3. Impact of postharvest calcium chloride ($CaCl_2$) treatments on the microbial load of *C. albidum* fruit stored at 28±2°C and 90±5% relative humidity for 15 days

Treatments	Storage (Days)	Bacterial Load (CFU/g) × 10^3	Fungal Load (SFU/g) × 10^3
At harvest	0	1.67 ± 0.67^{b}	6.00 ± 1.16^{b}
Control	15	198.42 ± 9.85^{C}	266.33 ± 24.66^{C}
1% $CaCl_2$ (5 Min)	15	0.08 ± 0.00^{a}	0.07 ± 0.00^{a}
1% $CaCl_2$ (10 Min)	15	0.06 ± 0.00^{a}	0.05 ± 0.00^{a}
1% $CaCl_2$ (15 Min)	15	0.03 ± 0.00^{a}	0.02 ± 0.00^{a}
2% $CaCl_2$ (5 Min)	15	0.03 ± 0.00^{a}	0.05 ± 0.00^{a}
2% $CaCl_2$ (10 Min)	15	0.01 ± 0.00^{a}	0.03 ± 0.00^{a}
2% $CaCl_2$ (15 Min)	15	ND	0.02 ± 0.00^{a}
3% $CaCl_2$ (5 Min)	15	0.02 ± 0.00^{a}	0.04 ± 0.00^{a}
3% $CaCl_2$ (10Min)	15	0.01 ± 0.00^{a}	0.02 ± 0.00^{a}
3% $CaCl_2$ (15 Min)	15	ND	0.02 ± 0.00^{a}

Means with the same letters within a column are not significantly different at $P<0.05$ using DMRT. Each value is the mean for three replicates. Abbreviations: ND: Not detected; CFU/g: colony forming units per gram; SFU/g: spore forming unit per gram.

Fruit Color

In this investigation, statistically significant differences were found between the control and $CaCl_2$ treated samples for all color characteristics (P>0.05). (Table 2). The sample's lightness was measured by the *L** value, its brightness was described by the *C** value, and the true color was represented by h^o value. As the number of storage days increased, the *L**, *a**, *b**, *C** and h^o values in all of the treated fruits declined. Skin color changes throughout storage; all fruits had values of 63.83 for L*, 21.19 for *a**, 45.79 for *b**, 50.46 for *C**, and 65.17 for h^o at the start of storage (Table 2). When harvested the color of fruits was brightly yellowish-orange but they gradually decrease as the storage days advanced. The loss of brightness of the pericarp as a result of browning may be responsible for the overall fall in the *L** value during storage. The h^o values followed the same pattern as *L**, *a**, *b**, and *C**. This pattern, a yellowish-orange color in contrast to the dark-green color of unripe fruit, is diagnostic of more advanced phases of ripening. The fruits treated with 1% $CaCl_2$ (5 min), 3% $CaCl_2$ (5 min), and 3% $CaCl_2$ (10 min) had the highest h^o values (58.73, 58.69, and 58.60) after 15 d of storage, while the control sample had the lowest (45.91). The control fruit samples revealed a lack of color development (reduction in h^o value) after 15 days, which could indicate browning and softening of the flesh. The *C. albidum* peel color changes could be a good criterion for determining the level of ripening. The findings of this study backed up Selcuk and Erkan's (2015) findings that rapid enzymatic browning occurred as medlar fruit softened throughout ripening, and significant changes in the color of the mesocarp, level of maturity, and skin color were seen throughout ripening and over-ripening. As a result of the findings in this study, $CaCl_2$ treatments have the potential to be used as an alternate color loss prevention strategy for fruit preservation at room temperature with a relative humidity of 90±5%. Food color is one of the most essential criteria for overall product approval and the most important aspect in consumer marketing of fruits and vegetables (Yikmiş, 2019). Fresh *C. albidum* fruits' skin color is the most crucial visual indicator of their quality and maturity.

Effect of $CaCl_2$ Treatment on Microbial Load of C. albidum Fruits at Ambient Storage

Table 3 shows the effect of $CaCl_2$ treatment on the microbiological load of *C. albidum* fruits. When compared to the control set, treated samples had reduced microbial counts. When the data were compared, it was shown that higher $CaCl_2$ concentrations resulted in a lower microbial load during storage. To control microbiological deterioration of *C. albidum* fruits, the most efficient concentration was found to be 2 and 3% (15 min). As the concentration and time of exposure increased, the data demonstrated a declining pattern for both bacterial and fungal counts during storage. The control had the highest fungal count (266.33×10^3 SFU/g), while the treated apples had much lower counts (Table 3). These numbers could be due to the fungi's ability to easily utilize the nutrients in the fruits for growth. The control had the highest bacterial count (198.42×10^3 CFU/g), whereas the fruits treated with 2 and 3% $CaCl_2$ had no bacterial count (15 min). These values were lower than the fungal loads, which are the most common cause of fruit and vegetable deterioration (Oranusi et al., 2012). This could be due to the extremely low pH. (3.27 - 4.30) recorded. Microorganisms are inhibited by increasing acidity and sugar concentration (Sartaj et al., 2013). The use of $CaCl_2$ dip treatments after harvest significantly reduced the microbial count in *C. albidum* fruits. In all of the fruit samples, no coliform load was recorded. As long as a suitable habitat is available, microorganisms will continue to propagate and multiply. Fresh commodities provide an ideal substrate for microorganisms, resulting in an increase in their population during storage. The diversity of these could be owing to the fruits' nutrient-rich nature, which encourages their growth and proliferation. According to Amusa et al. (2003), *C. albidum* fruits are rich in vitamins, iron, flavors, and essential minerals. The total bacteria count found in the treated fruit samples studied were below the normal board recommendation for fruits (1.0×10^2) (Falegan et al., 2017). According to the HACCP-TQM technical guidelines, raw foods containing < 10^4 CFU/g (< 4 log10 CFU/g), 10^4- 5×10^6CFU/g (4 - 6.7 log10 CFU/g), 5×10^6 - 5×10^7 CFU/g (6.7 - 7.7 log10 CFU/g) and > 5×10^7 CFU/g (> 7.7 log10 CFU/g) (number of spoilage microorganisms aerobic plate count at 70°F (21.1°C) are rated as "good", "average", "poor" and "spoiled food", respectively (Serkan et al., 2015). The treated samples' quality may be described as "good" in this investigation because the microbial loads reported were within permissible limits. The presence of $CaCl_2$, in combination with the low pH of the fruits, may be responsible for keeping the microbial count under control. The low count could also be due to calcium chloride's suppressive impact and the restrictions of growth in hermetic storage (Oranusi et al., 2012). $CaCl_2$ treatments can thus be employed as effective disease resistance, defensive mechanisms, and microbial growth control in *C. albidum* fruits preservation.

Conclusion

This study found that treating *C. albidum* fruits with 3% $CaCl_2$ for 15 min reduced microbial counts, preserved and maintained fruit appearance and some quality attributes during storage for 15 days, followed by dip treatment with 2% $CaCl_2$ for 15 min. $CaCl_2$ treatment has been safely used as a food additive for a long time. The procedure is simple to implement. It is affordable to store *C. albidum* fruits for 15 days at room temperature and 90 ± 5% relative humidity without significant changes in post-harvest quality attributes. In comparison to baseline values, fruit flesh firmness, *L**, *a**, *b**, *C**, and h^o values, pH, and microbial loads of the treated fruits decreased at the end of the 15 days, but titratable acidity content and weight loss increased. The weight loss of *C. albidum* fruits treated with $CaCl_2$ was lower than the control group, and the firmness values of these treated samples were higher than the control group, according to the findings of this study. These results show that $CaCl_2$ treatments could be a promising method for extending post-harvest life and maintaining *C. albidum* fruits quality during ambient storage. As a result, dipping *C. albidum* fruits in 3% $CaCl_2$ for 15 min may serve as an important post-harvest tool for maintaining quality and extending the fruit's storage life, potentially leading to increased consumer demand for "clean" fruits, lower total wastages, increased retail supply, higher profitability, and improved livelihood for *C. albidum* farmers and traders.

Conflict of Interest

The authors declared no conflicts of interest for this article.

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