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Preservation of Mango Fruit (*Mangifera indica* L., var Keitt) with Edible Coating of Starch Enriched with Garlic Extract During Storage at Ambient Temperature

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Abstract: Mango fruit plays an important economic role in Côte d'Ivoire as the third major exported fruit after banana and pineapple. The producing regions of mango fruits are in Northern of Côte d'Ivoire and the most cultivated varieties are Kent, Keitt and Amélie. The main issue of the mango value chain in Côte d'Ivoire is linked to poor agricultural practices and postharvest losses due to climateric characteristics of the fruit. The aim of this study was to investigate the efficiency of bioactive edible coating made of garlic extract and cassava starch as a novel approach to enhance the postharvest quality and shelf-life of Keitt mango fruit. Experimental approach was based on coating treatments by dipping Keitt mango fruits in cassava starch gel (2, 3 and 4%, w/v) with or without incorporation of garlic extract (4%, v/v). The use of edible coating highlighted the following results after 20 days of storage at ambient temperature: weight loss (10 – 14% FW); ratio TSS/TA (0.05 – 0.1), vitamin C (46 – 73% retention), total phenolic compounds (50 – 67% retention), antioxydant activity (62 – 69% retention). Moreover, garlic extract incorporated to cassava starch coating was found to have positive effects on extending postharvest quality characteristics of mango fruits. Overall, it was found that the coatings extended the self-life of Keitt mango fruits and improved their fresh quality compared to control after 20 days of storage at ambient temperature. It could be concluded that cassava starch coatings enriched with garlic extract might be a valuable alternative to extend the postharvest life of mango fruits.

Keywords: Cassava Starch, Edible Coating, Garlic Extract, Preservation, Keitt Mango

1. Introduction

Mango (*Mangifera indica* L.) is one of the five main tropical fruits in the world, with extensive marketing and production in 115 countries [1]. The annual production of mango fruit reached about 52 million tons according to FAO in 2020. Additionally, mango is considered as attractive fruit due to its color, delicious flavor, and nutritional characteristics [2]. In Côte d'Ivoire, mango fruit plays an important economic role as the third major exported fruit after banana and pineapple. The main producing regions (Korhogo, Ferkessedougou, Sinematiali, Boundiali, Odienne) of mango fruits are in Northern part of Côte d'Ivoire and the most cultivated varieties are Kent, Keitt and Amélie.

Despite the economic importance of mango in Côte d'Ivoire, it is well known that the fruit has limited postharvest life due to its climateric characteristics. For example, ripening ends eight (8) days after harvest for *Mangifera indica* L., var Tommy Atkins [3]. Thus, the high perishability of mango fruit makes it susceptible to several diseases, which cause significant postharvest losses up to 30-40% [4]. The degradation of the fruit is associated with several changes such as weight loss, reduced firmness,

pigments synthesis, increasing organic acids and sugars contents, respiration rate and ethylene synthesis [5]. Without using adequate preservation technologies, these biochemical processes can quickly lead to degradation of the fruit.

The reduction of postharvest losses would therefore improve the quality of the product and farmer's income. Recently, new postharvest technologies have been developed to extend the shelf life of mango fruit in response to market and consumer preferences. That is the case of using edible coatings from natural sources for fruit preservation [6]. Edible coatings are defined as thin layers of edible materials which that can be applied to the surface of food products by dipping, spraying, or panning [6, 7]. They act as a barrier to restrain the exchange of moisture and oxygen between the fruit and environment, leading to reduction in weight loss and respiration rate [8]. The composition of edible coatings can be divided into different groups, including lipids, resins, proteins and polysaccharides [9]. According to some authors [10], starch is the most natural biodegradable polymer used in edible coatings formulations and cassava is one the main plant source of starch in Africa.

Indeed, cassava starch is particularly useful as it is cheap, tasteless, odorless, colorless, nontoxic and transparent, thereby retaining the original taste, aroma, and appearance of the coated products [11, 12]. Recently, it has been shown that using cassava starch as edible coating is effective in improving the postharvest quality of various products such as 'Palmer' mango and 'Prata Anã' bananas [13, 14], cultivated in Colombia and Ecuador. Thefore, cassava starch-based coating appears as viable alternative in Ivory Coast, where cassava represents the second most important crop in the country [15].

Using edible coatings without some bioactive compounds may have some limitations regarding microbial contamination of fruits. Currently, there is a growing interest for incorporation of natural plant extracts, antimicrobial and antioxidant ingredients, bioactive compounds into edible coatings to improve the shelf-life of fruits and vegetables. Studies on using chitosan coating enriched with moringa leaf extract on avocado fruits and alginate coating incorporated with grape seed extract on grapes have demonstrated enhancement of the quality of fruits [16, 17]. Among natural plant extracts, garlic (*Allium sativum* L.) is a popular culinary plant due to its aroma and therapeutic properties that has long been used in traditional medicine [18]. The raw material (bulb) or processed products such as oil, water extract, and powder are known to possess antimicrobial and antioxidant activities due to high concentration of bioactive compounds, including organosulfur and phenolic compounds [19, 20]. To the best of our knowledge, there is currently no research reporting the effects of the cassava starch-based edible coating enriched with garlic extract on postharvest quality of tropical fruits. Therefore, the aim of this work was to investigate the efficiency of bioactive edible coating made of garlic extract and cassava starch as a novel approach to enhance the quality and shelf-life of Keitt mango fruit.

2. Materials and Methods

2.1. Fruits Samples

The mangoes fruits (*Mangifera indica* L., var Keitt) were collected in two orchards in the city of Korhogo (9°27′41″ North, 5°38′19″ West, Côte d'Ivoire), during 2020-2021 harvest season. The fruits without physical and physiological defaults, with similar color, size, and maturity level, were selected. They were carefully stacked in recyclable cardboard and transported within 24 h in ventilated conditions to Biotechnology Laboratory of Felix Houphouët-Boigny University (Côte d'Ivoire). Before coating, the mangoes fruits were washed in tapped water and sanitized with hypochlorite sodium solution (0,05% v/v). Then, they were rinsed with distilled water and air dried at room temperature.

2.2. Preparation of Edible Coatings and Experimental Treatments

2.2.1. Preparation of Garlic Extract

Two (2) kg of garlic bulbs (*Allium sativum*, vz. Mammoth Purple) were cleaned, washed with distilled water, and ground in a blender (Moulinex, France) to produce a visqueous suspension. Then, the suspension was filtered to discard the fibrous fraction. After filtration, the extracts were stored at 4°C before further use.

2.2.2. Coating Formulation and Treatement of Fruits

Briefly, three concentrations (2%, 3% and 4% w/v) of cassava starch gel coating (CC) were prepared and cooled at 50°C. For each concentration, garlic extract (GE) (4% v/v) was incorporated, mixed vigorously, and cooled at ambient temperature. The fruits were dipped in fresh coating solutions for 5 min to ensure a uniform coating. After, the fruits were air dried at room temperature and then stored at the room temperature (25 ± 2°C). The water dipped fruits were used as the control. A total of six treatments and control were investigated in this study (Table 1).

Table 1. *Experimental coating treatments for Keitt mangoes fruits.*

Groups	Treatments
Control	**Untreated**
T1 (CC 2%)	Dipping fruits in cassava starch coating (2%)
T2 (CC 2% + GE)	Dipping fruits in cassava starch coating (2%) + garlic extract (4%)
T3 (CC 3%)	Dipping fruits in cassava starch coating (3%)
T4 (CC 3% + GE)	Dipping fruits in cassava starch coating (3%) + garlic extract (4%)
T5 (CC 4%)	Dipping fruits in cassava starch coating (4%)
T6 (CC 4%+ GE)	Dipping fruits in cassava starch coating (4%) + garlic extract (4%)

Four (4) fruits were taken from each treatment and analyzed at 5 days interval till 20 days of storage. Fruits with three replicates (n = 3) in each treatment were used to determine postharvest quality characteristics.

2.3. Determination of Physical and Biochemical Properties of Fruits

2.3.1. Determination of Weight Loss

The fresh weight loss was estimated by weighting each sample fruit unit on a semi-analytical balance with an accuracy of 0.01 g. The difference between the initial and final weight was calculated and expressed as percentage (%) of weight loss.

2.3.2. Determination of pH, Titratable Acidity (TA), Total Soluble Solids (TSS), and TSS/TA Ratio

The values of pH, titrable acidity and total soluble solids (TSS) contents were determined after juice extraction. The pH value was recorded using a pH meter (Hanna Instruments). The titratable acidity was performed by titrating 5 mL of diluted juice with a solution of solution NaOH (0.1 N) using phenolphthalein as indicator. The results were expressed as percentage of citric acid (100 g-1 FW). The analysis of total soluble solids (TSS) was carried by a digital refractometer (Brand MILATO, Germany) and the results were expressed in °Brix units. Then, the TSS/TA ratio was calculated.

2.3.3. Determination of Reducing and Total Sugars Contents

Reducing sugars contents were estimated by the colorimetric method using 3,5-dinitrosalicylic acid (DNS). Aliquots of 500 µL of the total soluble solids aqueous extracts were mixed with 500 µL of DNS in test tubes. After stirring, the mixture was placed in a water bath at 100°C for 5 min. After cooling at ambient temperature, 4 mL of distilled water were added. The absorbance of samples was read using a UV–Vis spectrophotometer (Pioway Medical Lab, China) at 540 nm against blank. Reducing sugars content was obtained using a calibration curve of glucose (0.5 mg/mL) as standard. The results were expressed in grams of glucose 100 g^{-1} FW.

Afterwards, total soluble sugars contents were investigated. For this, 500 µL of total soluble solids aqueous extracts were added to 500 µL of phenol solution (5%, w/v) and 2.5 mL of concentrated sulfuric acid. After 30 min of incubation at room temperature, absorbance was read at 490 nm using UV-Vis spectrophotometer. Total solule sugars content was obtained using a calibration curve of glucose + fructose (0.5 mg/mL) as standardThe results were expressed in grams of glucose 100 g^{-1} FW.

2.3.4. Determination of Ascorbic Acid Content

The ascorbic acid (vitamin C) content was evaluated by titrating 5 mL of juice (stabilized with 2% metaphosphoric acid-acetic acid) using 2,6-dichlorophenol-indophenol (DCPIP) 0.5 g/L The results were expressed in milligrams ascorbic acid 100 g^{-1} FW.

2.3.5. Determination of Total Phenolic Content

The total phenolic content (TPC) was performed according to the method described by Singleton et al [21] using Folin-Ciocalteu's reagent. For total phenolic compounds extraction, 1 g of fruit pulp samples were homogenized with 10 mL of 70% (v/v) methanol. Homogenate was centrifuged at 6000 rpm for 10 min at room temperature. The supernatant was collected in a volumetric flask protected from light and stored for analysis further. An aliquot of 1 mL of the supernatant was oxidized with 1 mL of Folin-Ciocalteu's reagent for 3 min and neutralized by 1 mL of 20% (w/v) sodium carbonate. The reaction mixture was incubated in the dark for 30 min at ambient temperature. Absorbance was read in a UV-Vis spectrophotometer (Pioway Medical Lab, China) at 745 nm against a blank. Total phenol content was obtained using a calibration curve of gallic acid (1 mg/mL) as standard. The results were expressed as mg gallic acid equivalent 100 g^{-1} FW.

2.3.6. Evaluation of Antioxydant Activity

The total antioxidant activity was carried out using DPPH (2,2 diphenyl-1-picryl hydrazyl) reagent. About 50 µL of methanolic extract as described in 2.3.5. was added to 1.95 mL of DPPH (0.025 g DPPH in 100 mL of 70%, v/v methanol) and was allowed to react for 30 min in darkness at room temperature. The absorbance was read at 517 nm with UV-Vis spectrophotometer (Pioway Medical Lab, China). The negative control was prepared with DPPH and methanol to observe the decay of DPPH radical. The results were expressed as percentage of reduced DPPH.

2.3.7. Determination of Carotenoids Content

The carotenoids content was determined according to the procedure described by Howe and Tanumihardjo [22]. For this, 1 g of mango pulp sample was added with 5 mL of Butylhydroxytoluen (BHT): ethanol (0.1% w/v). The mixture was vortex stirred and heated at 85°C in water bath. A volume of 400 µL of KOH (80% w/v) was added to mixture for saponification. The mixture was homogenized and heated again at 85°C for 10 min. Afterwards, the reaction tubes were cooled in ice bath after a 3 mL of distilled water was added. Total carotenoids of samples were extracted twice with 4 mL of n-hexane and centrifuged at 4000 rpm for 10 min at room temperature. The supernatant (1 mL) was transferred to quartz cuvette and read on a UV-Vis spectrophotometer (Pioway Medical Lab, China) at 450 nm. Total carotenoid content was calculated by using equation including the absorbance (A), the volume V (mL) of the extract and the extinction coefficient of β-carotene ($A^{\%1\ cm}$ = 2592). The values were expressed in micrograms of beta-carotene 100^{-1} g FW.

2.4. Statistical Analysis

The data were investigated by analysis of variance (ANOVA), using the F test to verify the effect of treatments.

Polynomial regression analyzes were performed to test the linear and quadratic effects of the factors. We accepted equations that presented at least 5% significance by the F test and a determination coefficient higher than 0.5. The Duncan's test ($p \leq 0.05$) was used to compare the means between treatments and between storage days.

3. Results and Discussion

3.1. Weight Loss

Figure 1 shows the behavior of the weight loss of treated fruits and the control during storage at ambient temperature. The weight loss rate of all samples increased ($p < 0.05$) with the storage period and this rate was important in the control samples. The results also showed increasing of weight loss rate with the decrease of edible coating concentration (T2<T3<T4). Moreover, incorporation of garlic extracts into starch gel coating significantly ($p < 0.05$) reduced fresh mango weight loss as follow: 16.73% (T2) < 13% (T4) < 10% (T6) while control samples were around 20.60% after 20 days of storage. Generally, all coated fruits had much lower weight loss rate compared to uncoated ones. The effectiveness of reducing weight loss of mango fruit indicated that cassava starch coating acts a semi-permeable material [23]. The fact that the fruits coated with the highest concentrations of cassava starch (3% and 4%) had lower weight loss after 20 days of storage may be due to cassava moisture biofilm [24]. According to some authors [24], preventing weight loss by polysaccharide-based coatings is probably associated with the formation of hydrogen bonding between the hydroxyl groups of edible coatings and hydrophilic substances such as polyphenols. The results of this study agreed with findings reporting that the reduction of the weight loss rate of coated sweet cherry fruit during storage could be due to the presence bioactive compounds in the guar gum [25].

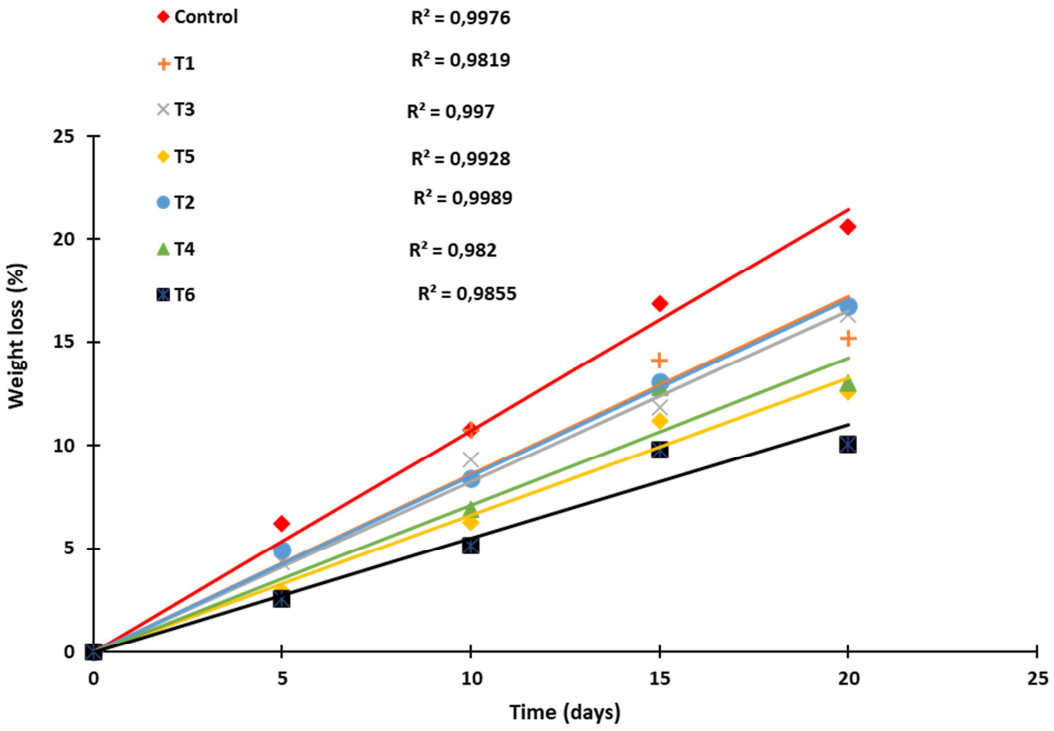

Figure 1. *Effect of coating treatments on weight loss of Keitt mango during storage at ambient temperature. Data represent the mean ± SD (n = 3). Control: uncoated fruits; T1: 2% cassava starch coating; T2: 2% cassava starch coating + garlic extract; T3: 3% cassava starch coating; T4: 3% cassava starch coating +garlic extract; T5: 4% cassava starch coating; T6: 4% cassava starch coating+ garlic.*

3.2. pH, Titrable Acidity and Total Soluble Solids (TSS)

During storage, increase in pH values was observed with lower values for the cassava starch-garlic coating system (Figure 2A). The values of titratable acidity were negatively correlated with pH (Figure 2B). The initial titratable acidity content was about 4% of citric acid, and this value quickly decreased in the uncoated fruit (0.35% of citric acid). However, all coated fruits had higher levels of titratable acidity content compared to uncoated ones. As is known, the maturation of climacteric fruits leads to the decrease of titrable acidity, and this phenomenon is attributed to the oxidation of organic acids [26]. Our findings suggested that cassava starch coating enriched with garlic extract, significantly prevented the loss of acidity. Similar results were obtained from study in which mango fruits were treated with guar gum in combination with essential oils [27].

The Figure 2C presented the behavior of total soluble solids (TSS) in all the treatments. It indicates that the total soluble solids contents were affected by the coating during

the storage period. The TSS contents of uncoated fruit increased and reached a maximum level at the end of storage period (19,43 ± 1,15 °Brix). However, the TSS contents in the coated group was lower. The results indicated that TSS contents in garlic extract group were as follow: 18,90% (T2) < 19% (T4) < 30,80% (T6) compared to control. In starch edible-based group, the values were 12,42% (T1) < 18,35% (T3) < 25,84% (T5). Our findings showed that using edible coating techniques caused lower increase in the total soluble solids than that observed for the control. Increasing of TSS contents during storage period was attributed to the conversion of starch into simple sugars like glucose, fructose, and sucrose in mango fruit [28]. Higher value of TSS contents recorded in uncoated fruits suggested that high amounts of starch were converted in mono and disaccharides during ripening process. In contrary, the edible coating decreased the ripening process of the fruit. The ratio TSS/TA or ripening index of uncoated mangoes gradually increased with the the storage period (Figure 3D). At the end of the storage, the highest ripening index was observed in the uncoated fruit (58,37%). However, coated fruits with garlic extract T6 (8,60%) showed a lower value compared to the control. The results indicated that uncoated mangoes ripened faster than the coated ones from the fifth day. Similar lower TSS/TA ratio have been reported for mangoes 'Palmer' using chitosan-based coatings [29], and for 'Mahali' mango coated with alginate edible coating [30].

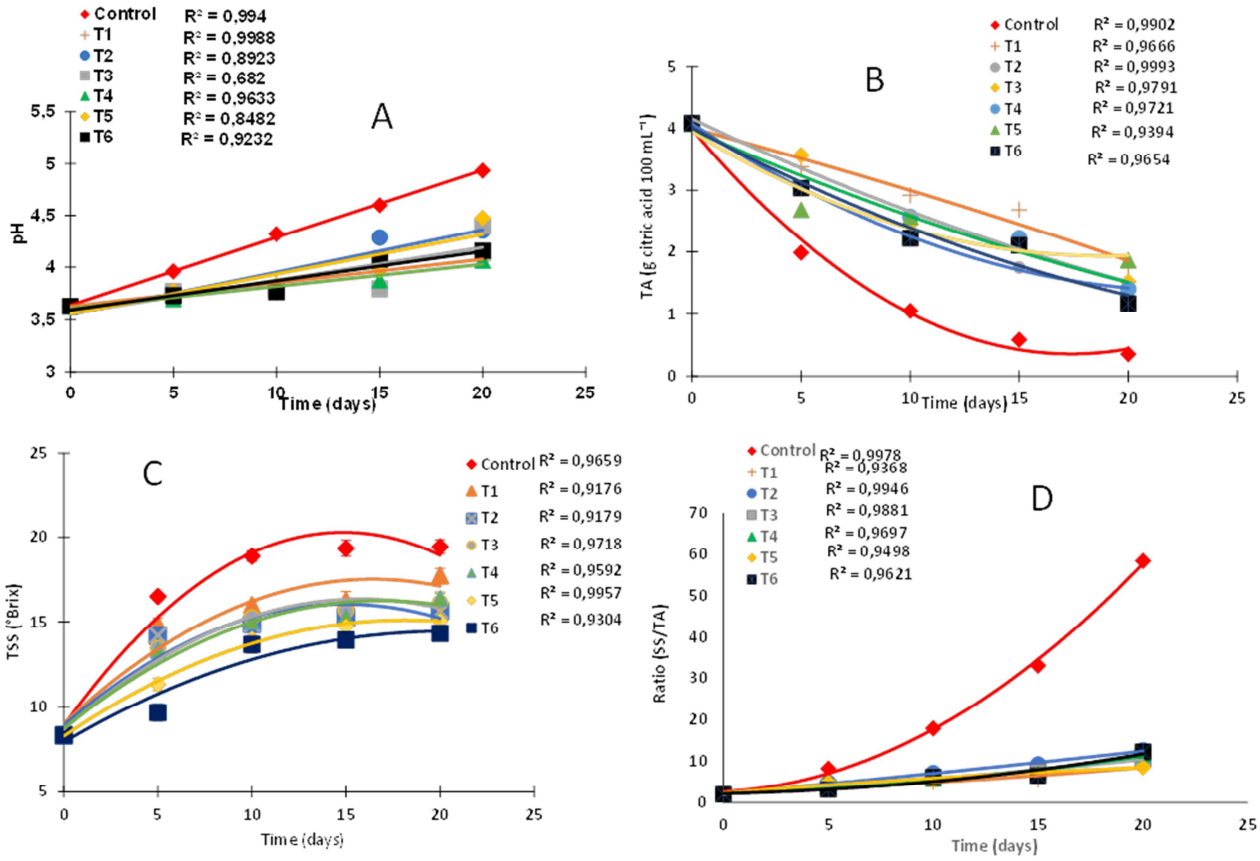

Figure 2. *Effect of coating treatments on pH (A), titrable acidity-TA (B), total soluble solids-TSS (C) and ripening index-TSS/TA (D) of Kent mango during storage at ambient temperature. Data represent the mean ± SD (n = 3). Control: uncoated fruits; T1: 2% cassava starch coating; T2: 2% cassava starch coating + garlic extract; T3: 3% cassava starch coating; T4: 3% cassava starch coating +garlic extract; T5: 4% cassava starch coating; T6: 4% cassava starch coating+ garlic.*

3.3. Bioactive Compounds Contents and Antioxidant Activity

Bioactive compounds are primary or secondary metabolites mainly found in vegetables and fruits where they possess antioxidant, anticarcinogenic, anti-inflammatory properties and may also protect the body against various diseases or metabolic disorders [31]. Among them, phenolics compounds are considered as the most important secondary metabolites that possess antioxidant potential by trapping free radicals produced during oxidative stress. They also promote auto-oxidation, chelation of metal ions and regulate the functions of enzymes [32]. Figure 3A depicted the changes in total phenolic compounds of mangoes for the coating treatments. At the end of storage, the T3, T4, T5 and T6 groups maintained higher total phenols content than the control. A similar observation has been reported for mango fruit stored in low temperature and coated with gum arabic enriched with calcium chloride [33]. The application of edible coatings with or without plant extract on fruit acts as a protective barrier to limit respiration and oxidation rate,

thereby leading to inhibit phenolic compounds degradation [34].

Moreover, the ascorbic acid (vitamin C) contents of treated mangoes were lower during the storage as compared to the untreated mangoes (Figure 3B). The results suggested that cassava starch coating enriched with garlic extract protected ascorbic acid form degradation. Indeed, the maturation of climacteric fruits affects ascorbic acid contents which decrease due to antioxidant activity [35]. It seems that the coating-based cassava starch incorporated with garlic extract restricts the permeability of oxygen, slows down the activity of enzyme and delays the oxidation reactions [36]. The carotenoids contents in mango pulp are directly related to the ripening stage. Figure 3C shows that the carotenoids contents increased with storage period for the treated samples. The control sample showed the highest increase ranging from 2.10 µg/g (green stage) to 14.80 µg/g of beta-carotene in the ripe stage. Using garlic extract in combination with cassava starch delayed the ripening of the treated fruits, which had lower carotenoids contents at the end of the storage period. The highest retention of carotenoids was found in T4 and T6 samples. The differences in carotenoids contents between coated and uncoated fruits may be related to the changes in metabolism by inhibiting ethylene synthesis and, consequently, chlorophyll degradation [37]. The antioxidant activity, determined by quenching rate of DPPH radical, was associated with the contents of total phenolics, ascorbic acid and carotenoids in fruits. Figure 3D indicated that the antioxidant activity decreased during storage period, showing difference between coated and uncoated fruits. The DPPH radical scavenging activity of the coated samples was higher than the control, so that highest antioxidant activity was observed for the T6 treatment (4% cassava starch + garlic extract) during storage. Results clearly showed higher levels of antioxidant capacity in mango treated with garlic extract incorporated in cassava starch coating. In previous study [37], similar results had been reported for Godji fruit. The use of coating could limit the reduction of bioactive compounds such as phenols and vitamins, which could improve antioxidant activity of the fruits.

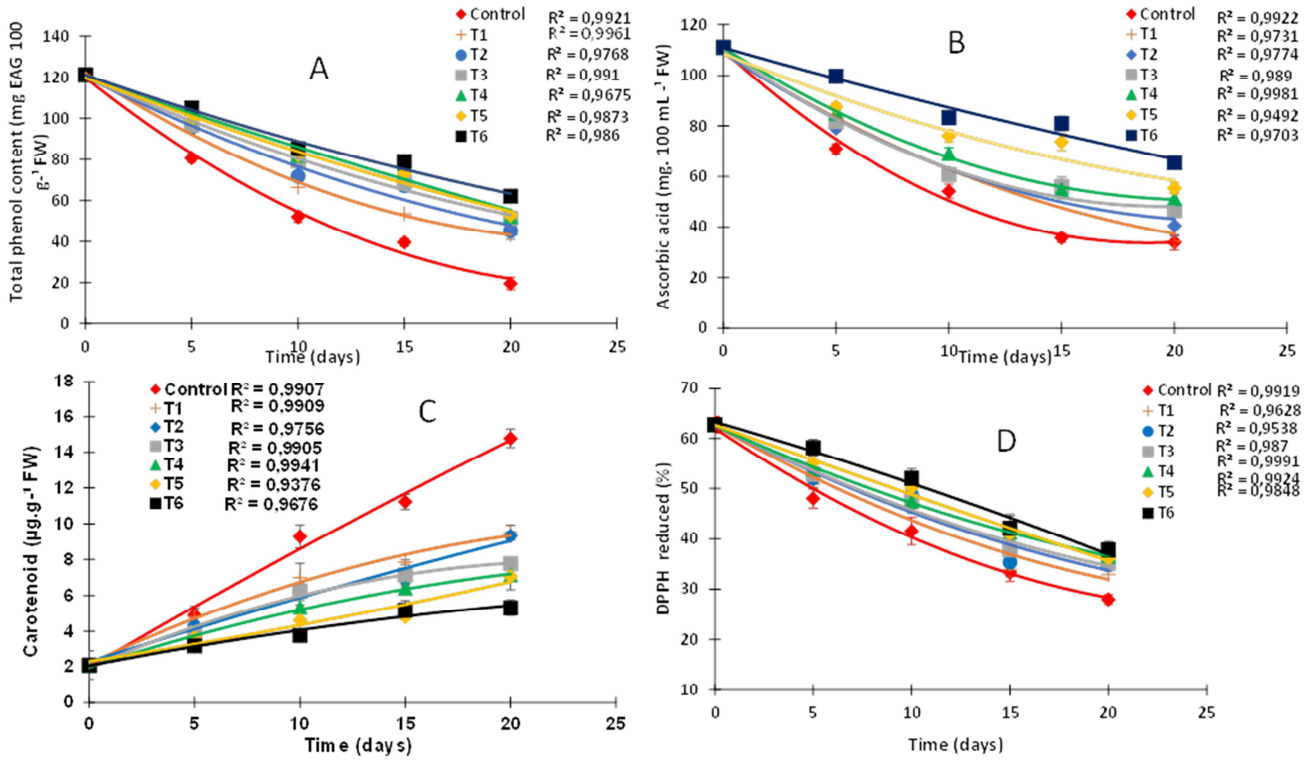

Figure 3. *Effect of coating treatments on total phenol content (A), ascorbic acid (B), carotenoid (C) and DPPH (D) of Keitt mango at ambient temperature. Data represent the mean ± SD (n = 3). Control: uncoated fruits; T1: 2% cassava starch coating; T2: 2% cassava starch coating + garlic extract; T3: 3% cassava starch coating; T4: 3% cassava starch coating +garlic extract; T5: 4% cassava starch coating; T6: 4% cassava starch coating+ garlic.*

4. Conclusion

The results of this study showed that the combination of garlic extract with cassava starch coating could improve the postharvest quality of Keitt mango and delay fruit ripening. Indeed, this novel coating procedure was efficient to reduce weight loss, maintained the titratable acid, soluble sugars contents and TSS/TA ratio. Degradation rate of bioactive compounds such as ascorbic acid, total phenolics was lower in coated fruits compared to uncoated fruits. Treatments with 3% and 4% cassava starch coatings enriched with garlic extract showed the best results in terms of preservation of the fruit. From these findings it could be concluded that, cassava starch coatings enriched with garlic extract might be a valuable alternative to extend the postharvest life of fruits. Further research work needs to evaluate the sensory acceptability of the coated mango fruits before commercial application.

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