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ASSESSMENT AND PERFORMANCE EVALUATION OF STARCH MODIFIED EDIBLE COATING AND FILM ON TOMATO PRESERVATION

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Abstract
This study explores the use of starch-modified edible coatings and films to enhance tomato preservation, addressing the need for improved post-harvest strategies. Through chemical modification of cassava starch by crosslinking, the films displayed enhanced water resistance, mechanical strength, and flexibility, making them effective barriers against microbial activity and moisture loss. Key results showed that the modified starch improved functional properties, including an increase in the oil absorption capacity of 8.05%. The formulation containing modified starch and guar gum (MSA) sample exhibited the highest DPPH scavenging ability (60.86%) and notable ABTS radical scavenging activity. Native starch, gelatin and guar gum (SGA) retained the highest lycopene content (0.56 mg/100g). Coatings made from the modified cassava starch outperformed native starch films in tensile strength and compressive resilience, resulting in an extended shelf life for coated tomatoes, preserving nutritional quality and reducing spoilage. These findings suggest that starch-modified coatings offer an effective, eco-friendly approach to prolong the post-harvest freshness of tomatoes, with implications for reducing food waste in agricultural supply chains.

Keywords: *Edible coating, starch, film, preservation, shelf-life*.

Introduction

All over the world, fruits and vegetables make up the largest part of waste and spoiled food through all areas of development (Abebe *et al*., 2017). Since they belong to living tissue and are incredibly fragile, fruits and vegetables require the proper technologies after being harvested in order to remain stable while they are stored and to have longer shelf lives (Kocira *et al*., 2021). One way to keep fruits and vegetables longer is to use biobased, biodegradable films and coatings (Dhaka and Upadhyay, 2018). These coatings are composed of edible, thin films that will prolong fruit and vegetable life by preventing them from spoiling, extending the amount of time they can be stored using other methods, and by protecting them from environmental harm due to single or multilayering properties associated with many composite types of materials that provide these types of services. The coatings created using these composite materials will be safe, functional and environmentally friendly (Radev and Pashova, 2020). Many of the food coatings used to date have resulted from the use of natural ingredient protein, lipid or polysaccharides (from either plant or animal sources) (Masina *et al*., 2017). However, there is a growing interest in assessing the potential of new coatings made from safe low-cost compounds that will not compete with or hinder the food supply chain or availability of food.

Agricultural waste valorization into *edible functional materials* is acknowledged as one of the strategies to utilize materials that are currently being disposed of, or underutilized (Masina *et al*., 2017).

Starch is the most abundant biopolymer; it is also agro-based in the manufacturing industry, due to its common availability, versatility, cost-effectiveness, high-energy content, ease of ease of modification, biodegradability and safety. These characteristics are what lead to starch's considerable level of acceptance in the food industry (Zia-ud-Din *et al*., 2017). It is not however common to use starch in its native state, due to some undesirable characteristics associated with raw or native starch such as freeze/thaw stability, low solubility, poor stability to pressure, poor thermal and shear stability; poor resistance to enzymatic hydrolysis, a high tendency for retrogradation and syneresis in starch (Ashogbon and Akintayo, 2013; Sumardiono *et al*., 2018). Native starch has been reported to be more functional when modified to improve its applicability for commercial use (Sugih *et al*., 2019). Starch can be modified via physical, chemical, enzymatic or a combination of techniques (Sondari *et al*., 2020). The most common method for modifying starch is by chemical modification, due to the high degree of control and precision obtainable in its modification. A detailed account of the different methods used in chemical modification is given in the works of (Singh *et al*., 2007; Ashogbon and Akintayo, 2013; Chen *et al*., 2015; Vanier *et al*., 2017; Wang *et al*., 2022b). By these, several functional characteristics can be altered and tailored towards specific uses.

The tomato (*Solanum Lycopersicum*) is an exceptional source of Vitamins A, B, C and E (Arah *et al*., 2018). It contains several bioactive compounds, such as carotenoids, chlorophyll, organic acids, flavonoids, lycopene, and phenolic compounds that offer health benefits by reducing the incidence of cardiovascular diseases (Mahieddine *et al*., 2018; Dominguez *et al*., 2020). Although tomatoes are a source of many nutrient-dense foods and other phytochemicals that promote health, their postharvest shelf-life is short due to many factors including rapid water loss, postharvest diseases, the ripening process and senescence affect marketing and transport of tomatoes (Nawab *et al*., 2017). Studies have found that an estimated 50% of the total global tomatoes produced are lost during handling and as a result, are responsible for significant financial losses and significant contributions to environmental degradation (Torres-Leon *et al*., 2020). Therefore, exploring new methods of preserving tomatoes is essential to reducing waste and extending the their shelf-life. The use of edible films and coatings is one of the methods by which the quality of tomatoes can be kept intact and food waste can be minimized by extending the postharvest shelf life and reducing quality loss. They have been reported to preserve the nutritional values in fruits and vegetables (Swathi *et al*. 2017; Patanè *et al*., 2020) and are safe and suitable for human consumption because they are produced from natural materials that are generally regarded as safe (GRAS) (Khalil *et al*., 2020).

Materials and Methods

Sources of Raw Materials

The freshly harvested cassava roots and tomatoes used were purchased from research farm of Federal University of Technology, Akure and authenticated in FUTA herbarium. All the chemicals used for the starch modification were of analytical grade.

Extraction of Cassava Starch

The modified method described by Benesi et al. (2004) was used for the extraction of the native cassava starch. Freshly harvested cassava roots were washed, peeled, chopped and then pulverized in a highspeed blender for 5 min. The pulp was suspended ten times its volume of water, stirred for 5 minutes and then filtered with the use of double fold cheesecloth. The filtrate was allowed to stand for 2 h for the starch to settle and the top liquid was decanted and discarded. Water was added to the sediment and the mixture was stirred for 5 min. Filtration was carried out with the use of double fold cheesecloth and the starch from the filtrate was allowed to settle. After decanting the top liquid, the starch was dried in an oven at 60 ℃ for 12 h and stored for further treatment.

Starch Modification

The native cassava starch was modified according to the method described by (Akpa and Dagde, 2012) with little changes. 1200 g of native cassava starch was weighed into a plastic container, 1.2 g of silicon oxide (fluxing agent) was added and mixed for 5 min. 120 g of sodium hydroxide was added as a catalyst, mixed for 20 min. The mixture was then mixed for 15 min with a 174 g of sodium acetate (cross linking agent). The whole mixture was heated in a water bath maintained at a temperature of 75° C, while stirring continuously for 1 hour. It was then poured out to cool.

Film Formation and Coating

A modification of the method described by Sandhu et al, 2020 was used in the formation of the starch-based edible film. The starch poured in a clean container was stirred with distilled water for 10 min. A separate container was prepared to mix guar gum (3%), gelatin (3%) and distilled water thoroughly 40 min and the mixtures in both containers were added together. 5 % Glycerol was added to the mixture and stirred for 10 min. The mixture was divided into two, a part was used in the coating of the freshly

harvested tomato samples by dipping them into the mixture and stored in a cool and dry room for observations and further analysis. The other part, however, was poured into petri dishes, dried at 38 ℃ for 8 h. The films were later peeled off and stored for further analysis. This procedure was carried out on each of the four edible film samples containing modified starch (MAG), guar gum and gelatin, sample (SGA) containing native starch, guar gum and gelatin, sample (MSG) containing modified starch and gelatin and sample (MSA) containing modified starch and guar *gum.*

Pasting Properties

The pasting properties of the starch samples were determined according to method described by Oyeyinka *et al*., 2020 using a Rapid Visco-Analyzer (RVA 4500, Perten Instruments). 2.5 g of each starch samples (native and modified cassava starches) was mixed with distilled water. The mixture was agitated by mixing manually using a plastic paddle before inserting the canister into the instrument. The starch was stirred at 960 rpm for 10 seconds before the shear input was decreased and held constant at 160 rpm during the subsequent heating and cooling cycles. The peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature of the samples were obtained from the software with the instrument.

DPPH, ABTS Free Radical Scavenging Activity and Ferric Reducing Activities of the Extract

The free radical scavenging ability of the extract against DPPH (1, 1- diphenyl-2-picryhydrazyl) was carried out using the method described by Gyamfi *et al*. (1999). 1 ml of the extract was mixed with 1ml of the 0.4 mM methanolic solution of the DPPH and the mixture was left in the dark for 30 min before measuring the absorbance at 516 nm. ABTS scavenging ability of the extract was determined according to the method described by Re *et al*. (1999) while the reducing property of the extract was determined by the method reported by Pulido *et al*. (2000)

Microbial Load Reduction Potential

A sterile knife was used to cut each tomato sample into small pieces, and 10 g of the sample was crushed in a sterilized mortar. The crushed tomato samples were then transferred into separate dilution bottles containing 9 ml of sterile saline solution. The content of each bottle was mixed thoroughly before performing serial dilutions up to 10^{-6}. From the final dilutions, 1 ml of the mixture was seeded into agar plates labelled as NA (nutrient agar), PDA (potato dextrose agar) and MRS (De Man-Rogosa-Sharpe agar). Each of the sterilized agars were poured into the corresponding agar plates and were allowed to gel on the sample. The plates were then incubated at 37 ℃ for 24 h for (NA and MRS) and 72 h at 25 ℃ for (PDA). After incubation, microbial colonies formed were counted and the numbers were recorded.

Functional Properties

Foaming properties

The method described by Narayana et al. (1982) was followed to determine the foaming capacity (FC) and foaming stability (FS). 1.0 g of the native and modified cassava starch sample each was transferred to separate graduated cylinders and diluted with 50 mL of distilled water at 32 ºC. Foam formed after the suspension was shaken for 5 min and the foaming capacity was derived from the volume of foam at 30 seconds post-whipping as described in Equation 1:

$$\text{Foaming capacity} = \frac{(\text{Volume of AW} - \text{Volume of BW}}{\text{Volume of BW}} \times 100 \quad (1)$$

Where, AW = after whipping, BW = before whipping.

Foaming stability was calculated as a percentage of the initial foam volume by measuring the volume of the foam 1 h after whipping.

Solubility and swelling power

Solubility and swelling power were determined according to the method employed by Adebowale et al. (2000) with few changes. 1.0 g of the native and modified cassava starch sample each, were transferred to different pre-weighted 50 mL centrifuge tubes and stirred after adding 40.0 mL of distilled water. The mixtures were heated at 55, 65, 75, 80, 85 and 95 ºC while being stirred constantly for 30 min and later centrifuged at 2200 rpm for 15 min after being cooled to room temperature. The supernatants were poured into crucible that had been previously weighed and then heated until it evaporated. Solubility was determined by measuring the amount of solid that remained in the crucible after the liquid had been removed as described by Equation 2.

$$\text{Solubility \%} = \frac{(\text{Weight of dried sample in supernatant})}{\text{Weight of original sample}} \times 100 \quad (2)$$

The swelling power was calculated by measuring the weight of the paste in the tube and plugging the results into the Equation 3:

$$\text{Swelling power \%} = \frac{\text{Weight of wet mass of sediment}}{\text{Weight of dry matter in the gel}} \times 100 \quad (3)$$

Table 1: Pasting Properties of the Native and Modified Cassava Starches

Samples	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (min)	Pasting Temperature (°C)
Native starch	7785.03 ± 0.04 [a]	2332.02 ± 0.03 [a]	5453.02 ± 0.03 [a]	3202.01 ± 0.01 [a]	870.01 ± 0.02 [a]	3.87 ± 0.00 [b]	71.95 ±0.0 0 [a]
Modified starch	2024.01 ± 0.01 [b]	1788.02 ± 0.02 [b]	236.01 ± 0.01 [b]	1788.02 ± 0.03 [b]	0 ± 0 [b]	6.67 ± 0.00 [a]	50.31 ± 0.01 [b]

Results are mean values of duplicate determination ± standard deviation. Mean values within the same column having the same letter are not significantly different at p<0.05.

Water absorption capacity (WAC)

The WAC of the samples were evaluated following the method developed by Fontes et al. (2017) with slight modification. 1.0 g of native and modified cassava starch sample each was transferred into different 50 mL centrifuge tubes. 40.0 mL of distilled water was added followed by shaking for an hour. The resulting slurry was centrifuged at 2200 rpm for 15 min. The supernatants were drained off as much as possible with soft tissue paper. The amount of water absorbed was calculated in grams by 100 grams of sample.

Bulk density

The bulk densities of the native and modified starch samples were determined using the method of by AOAC (1990) as described in Equation 4. Exactly 10 mL capacity graduated measuring cylinders were weighed and gently filled with the samples. The bottom of each cylinder was tapped several times until there were no further diminution of the sample level after filling to the 10 mL mark.

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of Sample}}{\text{Volume of Sample}} \quad (4)$$

Oil absorption capacity

The procedure of Adeleke (2014) was used to determine the oil absorption capacities of the starch samples. Instead of water, refined soybean oil with density of 0.92 g/mL was used. The oil and the starch blends (1.0 g starch in 10 mL oil) were mixed using a magnetic stirrer at 1,000 rpm for 5 min and then centrifuged at 3500 rpm for 30 mins. The amount of oil separated as supernatant was measured using 10 mL cylinder. The difference in volume was taken as the oil absorbed by the samples. The oil absorbed was expressed as g/mL of oil absorbed.

Emulsion capacity

Emulsions were prepared according to a modified version of Aidoo et al. (2022) [36] method adapted for cassava starch. 2 g each of the native and modified cassava starches were blended using a Moulinex electric blender with 5.0 mL of oil in 100 mL **o**f distilled water for 30 seconds at high speed. During the blending, additional oil was added in 5 mL portions while maintaining high-speed blending. The point at which there was a noticeable drop in consistency (from maximum resistance), subjectively observed by a decrease in resistance to blending, was considered the point of discontinuation of oil addition. The total amount of oil added until this point was recorded as the emulsifying capacity of the cassava starch sample. The prepared emulsion was then allowed to stand in a graduated cylinder, and the volume of separated water was measured over time to assess the emulsion's stability.

Mechanical Property of the Film

The mechanical compression test (extension at break, strain at break, load at break, energy at break and young modulus) on the different edible film samples was carried out according to the ASTM D-695 method (ASTM, 2010). The mechanical tensile test (elongation at break, strain at break, load at break, stress at break, energy at break, and young modulus) was measured using a texturometer (TA.XT Plus Texture Analyzer, Stable Micro Systems) according to the ASTM D-882 method (ASTM, 2000).

Statistical Analysis

The data obtained were analyzed using one-way analysis of variance (ANOVA) and means were compared using the Fisher Least Significant Difference (LSD) test ($p \leq .05$) using the Statistical Package for the Social Sciences (SPSS) Version 21.0 for Windows (SPSS Inc.).

Table 2: Antioxidant Properties Tomato Samples Coated with Edible Films

Samples	DPPH (%)	ABTS (mg/ml)	FRAP (mg/ml)	Lycopene (mg/100g)
MAG	51.27 ± 0^{c}	11.17 ± 0^{c}	0.30 ± 0^{c}	0.35 ± 0^{d}
SGA	49.72 ± 0^{d}	10.65 ± 0^{f}	0.20 ± 0^{f}	0.56 ± 0^{a}
MSG	49.17 ± 0^{e}	10.99 ± 0^{d}	0.26 ± 0^{e}	0.38 ± 0^{b}
MSA	60.86 ± 0^{a}	11.45 ± 0^{b}	0.30 ± 0^{d}	0.16 ± 0^{e}
CRI	51.27 ± 0^{c}	10.97 ± 0^{e}	0.38 ± 0^{a}	0.37 ± 0^{c}
CUR	59.76 ± 0^{b}	12.49 ± 0^{a}	0.37 ± 0^{b}	0.14 ± 0^{f}

Results are mean values of duplicate determination ± standard deviation. Mean values within the same column having the same letter are not significantly different at $p<0.05$.

KEYS: MAG=Modified starch, Guar gum, Gelatin; SGA= Native starch, Guar gum, Gelatin; MSG=Modified starch, Gelatin; MSA=Modified starch, Guar gum.

Results and Discussion

Pasting properties

The pasting properties of the native and modified cassava starches are presented in Table 1. Native starch had higher peak, trough, breakdown, final, setback viscosities and pasting temperature while modified starch had a higher peak time. Peak viscosity is a measure of the highest viscosity a starch granule can attain before collapsing (Adebowale *et al*., 2005). The peak viscosity of the starches ranged from 2024.01 RVU to 7785.03 RVU. It was observed for this study that the modification treatment reduced the peak viscosity of the cassava starch which is in line with what was reported by Adeleke (2014). The trough viscosity of the starches range between 1788.02 RVU to 2332.02 RVU, with the modified starch having a lower trough. This low trough viscosity is an indication that the modified starch samples can withstand break-down during cooling and the result agrees with Iwe *et al*. (2001), who reported that high trough viscosity indicates the tendency of breakdown in viscosity during cooling. The breakdown viscosity of the starches ranged from 236.01 RVU to 5453.02 RVU and differed significantly ($p \leq 0.05$) from one another. The modified cassava starch had a low breakdown viscosity. Breakdown Viscosity is the measure of the degree of susceptibility of the starch granules to shear stress and thermal agitation (Adeleke, 2014). A high breakdown viscosity value indicates significant degradation of the starch. granules leading to less stable gel. Modification by crosslinking generally reduces breakdown by reenforcing the starch granules, making them more resistant to degradation.

The final viscosity of the starches ranged from 1788.02 RVU to 3202.01 RVU and differed significantly ($p \leq 0.05$) from one another. The modified cassava starch had a low final viscosity compared to the native starch. Final viscosity, which shows the starch's capacity to form a viscous paste after cooking and cooling, is frequently used to assess the quality of specific starch-based flour. Additionally, it provides a measurement of the paste's resistance to shear force under stirring (Austin, 2024). The setback viscosity of the starch samples ranges from 0.00 RVU to 870.01 RVU. The values obtained revealed that native cassava starch had the highest setback viscosity than the modified starch sample and there is a significant difference ($p \leq 0.05$) between the starches. Adebowale (2005) reported a setback viscosity of 72.67RVU for cassava starch, lower than 870. 01 RVU but higher than 0.00 RVU obtained from this present study for native and modified cassava starches respectively. The texture of different products has been linked to setback, and excessive setback has also been linked to syneresis or weeping during freeze/thaw cycles (Maziya-Dixon *et al*., 2011). The peak time required to attain the peak viscosity for the starch samples ranged from 3.87 to 6.67 minutes. The peak time of the two samples showed significant differences ($p \leq 0.05$) from each other. It took the modified starch 6.67 min to attain peak viscosity while the native cassava starch attained a peak viscosity at a lesser peak time (3.87 min). The high peak time value of the modified cassava starch indicates that it began to form paste later than the native starch sample. Two novel cassava accessions' starch showed a greater peak time of 6.9 and 6.7 min, respectively. The native and modified starches gelatinized at temperature 71.95 ℃ and 50.31 ℃ respectively. The pasting temperature of the starch samples showed significant differences ($p \leq 0.05$) from each other. Native cassava starch exhibited the highest pasting temperature (71.95 ℃) while the least pasting temperature was seen in the modified starch sample

(50.31 ℃). It was observed that the modification treatment reduced the pasting temperature of the starches. Higher pasting temperatures of 81.68 ℃ for cassava starch was reported by Adebowale (2005). In addition to being crucial for controlling energy expenses and the stability of other food ingredients in a product, the pasting temperature indicates the lowest temperature needed to cook or gelatinize starch (Kaur and Singh, 2005).

Antioxidant Activity

The in - *vitro* antioxidant capacity of the film samples are shown by the results in Table 2. DPPH radical is a lipid free radical that becomes a stable product after accepting an electron or hydrogen from an antioxidant (Kedare and Singh, 2011). The ability of the various film samples to scavenge the DPPH citation radical antioxidant activity was measured and MSA (60.86%) showed the highest level of DPPH scavenging ability among the films used in coating the tomato samples, while sample MSG (49.17%) which is the film containing modified starch and gelatin showed the lowest scavenging ability. It was found that the addition of guar gum to the modified starch during the film formation resulted in an increase in its antioxidant activity. The high antioxidant activity may be because guar is a polysaccharide that has a high capacity to form gels and films (Arfat et al., 2017), providing a matrix that can trap and stabilize bioactive compounds. The presence of hydroxyl groups in guar gum facilitates better interaction with antioxidant compounds, enhancing their bioavailability and activity. Saha *et al.* (2016) studied the effect of guar gum-based films on fresh cucumber and reported that the antioxidant activity improved.

ABTS is one of the substrates used to evaluate antioxidant activity of bioactive compounds. The ABTS radical scavenging abilities of the coated and uncoated tomato samples were tested and results indicating a range of antioxidant activity from 10.97 – 12.49 mg/ml were obtained with MSG having the highest ABTS value followed by MSA (11.45 mg/ml) among the other samples, indicating strong antioxidant capacity. The sample SGA had the least ABTS value of 10.65 mg/ml. Unripe tomatoes generally contain higher levels of certain antioxidants like flavonoids, phenolic compounds, and vitamin C.

These compounds tend to be more concentrated during the early stages of ripening, as they play a role in the plant's defense mechanisms. As tomato ripens, some of these antioxidants decrease, while others like lycopene increases. However, lycopene has lower ABTS scavenging ability compared to phenolic compounds and flavonoids, contributing to a lower ABTS value in ripe tomatoes. In a previous study, Naeem et al. (2010) reported that the antioxidant capacities, ascorbic acid, lycopene, carotenoid, phenolics and flavonoid of guar gum coated green-unripe mangoes were maintained during storage. The higher DPPH value of 11.45 mg/ml in sample MSA among the coated samples may be because of the synergistic effect of the modified starch and guar gum creating a more stable matrix that improves the retention of antioxidants.

The FRAP assay measures the presence of reducers (i.e., antioxidants) which result in reduction of the Fe^{3+} complex to the ferrous form Fe^{2+}. All the tomato samples had significantly reducing power, but uncoated ripe tomato sample (CRI) had significantly stronger reducing power with a FRAP value of 0.38 mg/ml followed by samples CUR (0.37 mg/ml), MAG and MSA (0.30 mg/ml). The sample SGA had the least FRAP value of 0.20 mg/ml. Coatings from materials such as starch, guar gum, and gelatin, can encapsulate or trap antioxidants within the matrix of the film. This encapsulation hinders the ability of antioxidants to move freely and engage in redox reactions required for the FRAP assay. As a result, the antioxidants are less effective in reducing ferric ions, leading to a lower FRAP value for coated tomatoes. The tomato samples coated with modified cassava starch, guar gum and gelatin (MAG) and modified cassava starch and guar gum (MSA) had the highest FRAP value among the coated samples. The result also showed that the films made with modified starch had a higher FRAP value than the films made with native starch indicating that film from modified starch has a higher reducing ferric ion property.

Lycopene is the carotenoid pigment responsible for the red colour of tomato and it is known to have potential health benefits (Naeem *et al*., 2018). As tomato ripens, the lycopene content increases. The result showed that the tomato sample (SGA) had the highest lycopene content of 0.56 mg/100g while the tomato sample (MSA) had the lowest lycopene content 0.16 mg/100g among the coated samples. Oxygen is considered as key substrate for the activity of the ripening enzymes (Cruz *et al*., 2018). In edible-coated tomatoes, the edible coating provides a barrier to oxygen, thereby slowing down the activity of enzymes and delaying the ripening-associated changes in tomato (Yadav *et al*., 2022). This result shows that the composite film from native starch, gelatin and guar gum had a low oxygen barrier property which led to the fast ripening of the coated tomato during storage resulting in a high lycopene content while the composite film from modified cassava starch and guar gum slowed down the ripening process due to its strong oxygen barrier properties. A study by Dávila-Aviña (2014) reported that edible coating

significantly reduced the changes in lycopene content as compared to uncoated samples after 28 days of storage at 10°C.

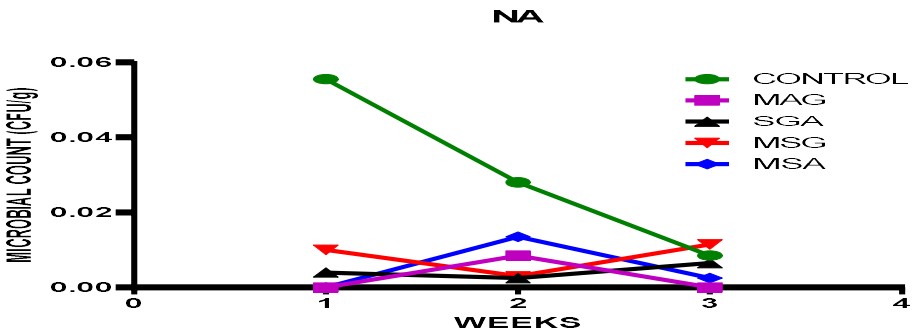

Figure 1: Microbial growth on the samples in Nutrient agar (NA)

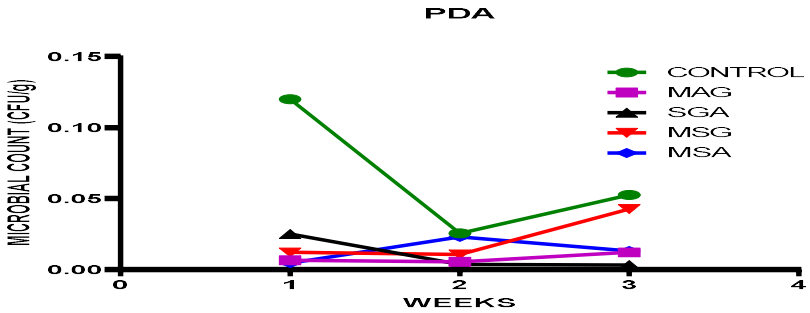

Figure 2: Microbial growth on the samples in Potato Dextrose agar (PDA)

Figure 3: Microbial growth on the samples in De Man-Rogosa-Sharpe agar (MRS)

KEYS: MAG= Tomato coated with modified starch, guar gum and gelatin, SGA= Tomato coated with Native starch, gelatin and guar gum, MSG= Tomato coated with modified starch and gelatin, MSA= Tomato coated with modified starch and guar gum.

Microbial Load Reduction Properties

The microbial growth on the samples, as shown in the Figures 1, 2 and 3, offers information on the efficacy of the various treatments applied to tomatoes using different combinations of starches (native and modified), gelatin and guar gum. The effectiveness of the treatments was determined on three different media: Nutrient Agar (NA), Potato Dextrose Agar (PDA), and De Man-Rogosa-Sharpe agar (MRS). Each sample was monitored over three weeks.

On the Nutrient Agar (NA) medium, which is intended to stimulate the growth of a wide spectrum of bacteria, the control sample had the highest microbial count, consistently outnumbering the treated samples over all weeks. This indicates that untreated tomatoes are more prone to microbial infection. The samples treated with modified starch-based formulations (MAG, MSG, and MSA) had the lowest microbial growth compared to the samples treated with native starch (SGA).This is expected, because the modified starch may have better

antibacterial characteristics and operate as a more effective barrier, minimizing bacterial contamination.

The combination of modified starch with other components, such as guar gum or gelatin, also contributed to the film's ability to inhibit microbial proliferation. The treatment with MAG (modified starch, guar gum and gelatin) produced the lowest microbial count (CFU/g). This demonstrates the efficiency of employing modified starch mixed with guar gum and gelatin, which presumably boosts the film's ability to operate as a barrier against microbial contamination (Pérez-Gago and Krochta, 2007).

The results from the PDA medium, which is selective for fungi, showed that modified starch treatments (MAG, MSG, and MSA) gave stronger resistance to fungal colonization on tomatoes than native starch (SGA) due to their altered molecular structure, which impeded fungal attachment. While native starch treatments (SGA, which included starch, gelatin and guar gum) reduced fungal growth, they were not as effective as modified starch treatments. This is consistent with earlier research emphasizing the increased moisture barriers and antibacterial characteristics of modified starches. Gelatin and guar gum in the SGA formulation further improved fungal inhibition by forming a semi-permeable barrier, which increased the films' antimicrobial activity. Overall, the modified starch treatments outperformed native starch in reducing microbial counts on PDA, although native starch combined with gelatin and guar gum still demonstrated some microbial resistance. The control sample exhibited higher microbial counts compared to the treated tomatoes.

Microbial counts in the MRS medium were generally lower, indicating that the medium's unique microbial communities have a low growth potential. The MRS culture medium, which is normally selective for lactic acid bacteria, illustrates how edible film components interact with the microbial community that causes spoilage. Once again, the MAG treatment outperformed the others, further reinforcing that modified starch coatings are superior for microbial control. The presence of guar gum and gelatin, which can affect the texture and permeability of the film, may also have influenced microbial activity by creating conditions less favorable for bacterial growth (Thakur et al., 2019). In all tested media, the control samples consistently showed the highest microbial growth, demonstrating the effectiveness of edible films and coatings. Treatments with modified starch (MAG and MSA) consistently outperformed native starch treatments (SGA), supporting the hypothesis that starch modification enhances the antimicrobial properties of coatings (Pérez-Gago and Krochta, 2007). This is likely due to the improved film-forming abilities and barrier properties resulting from starch modification.

Functional Properties

The functional properties of the native and modified starches are presented in Table 3. Between native and modified starch, bulk density, which represents the weight of the starch per unit volume remained constant, indicating just a minor change (0.77 g/ml for both, ±0.01 for modified). This consistency shows that the structural compactness or particle size of the starch grains was not altered by the modification technique applied in this study. The formulation of edible films depends much on bulk density since it affects the film's packing behavior and general texture. Other investigations have found that crosslinking has little effect on the compactness of starch granules, resulting in identical bulk densities (Adebowale *et al*.,2005).

Table 3: Functional properties of Native and Modified starch

FUNCTIONAL PROPERTIES	Native Starch	Modified Starch
Bulk density (g/ml)	0.77 ± 0.00	0.77 ± 0.01
Oil Absorption Capacity (%)	7.40 ± 0.10	8.05 ± 0.05
Water Absorption Capacity (%)	31.50 ± 0.50	29.10 ± 0.50
Foaming Capacity (%)	15.00 ± 1.00	17.50 ± 1.00
Swelling Index	0.75 ± 0.03	0.77 ± 0.01
Emulsion Capacity (ml/100ml)	58.78 ± 0.55	56.71 ± 0.60

All values are mean ± SD of three replicates.

The modified starch had a higher oil absorption capacity, OAC, (8.05%) than native starch (7.40%). This increase implies that the modified starch may bind and hold oil more effectively, which can be attributed to changes in surface hydrophobicity caused by the crosslinking process. Increased OAC improves barrier qualities against oil migration, resulting in a more stable film. This higher OAC is useful in food coatings because it improves the barrier qualities against oil migration, resulting in a

more stable film. This finding is congruent with that of Alimi (2021) who found that crosslinked starch improves lipid interactions, making the film more successful in food applications involving oil-based ingredients. In contrast, modified starch has a water absorption capacity (WAC) of 29.10%, down from 31.50% in native starch. This decline shows that crosslinking or other modification procedures reduce the availability of hydroxyl groups that bind water molecules, hence reducing the starch's ability to absorb water. A lower WAC for edible films means that the coating is less likely to expand in humid situations, which improves stability, particularly in food coatings. This supports the findings of (Wang et al., 2022b), who discovered that crosslinked starch films inhibited water uptake, resulting in longer shelf life for coated fruits.

The foaming capacity of a food or flour is measured as the amount of interfacial area created by whipping the food or flour. Foam stability measures the time required to lose either 50 percent of the liquid or 50 percent of the volume from the foam (Mauer, 2003). Foaming Capacity (FC) increases from 15.00% to 17.50% in modified starch, indicating that structural changes enhance the starch's ability to trap air and form a stable foam. The improved foaming ability in the modified starch is likely related to changes in surface-active properties due to the modification process, which can enhance the protein-starch interaction, making it more effective in forming and stabilizing foam. Similar findings were reported by Singh *et al*. (2007) who observed improved foaming properties in modified starch.

The swelling Index increased slightly from 0.75 in native starch to 0.77 in modified starch. Although minimal, this rise indicates improved water-holding capacity and film flexibility, but not enough to dramatically affect its overall swelling behavior. Modified starches typically show regulated swelling, which is necessary for food products that require thickening without excessive viscosity (Singh *et al*., 2007). The modified starch-based coatings may be better suited for sensitive surfaces like tomatoes.

Emulsion Capacity (EC) dropped from 58.78 ml/100 ml in native starch to 56.71 ml/100 ml in modified starch. The decline could be attributed to changes in the surface characteristics of starch granules after alteration, which may affect their ability to stabilize oil-water interfaces. This implies a decrease in the starch's capacity to produce stable emulsions, probably due to increased hydrophobicity, as highlighted by Zhang (2020). A study by Guimarães et al. (2018) reported similar observations, noting that crosslinked starches tend to exhibit reduced emulsification efficiency. Although a lower emulsion capacity can affect the uniformity of the coating, this can be adjusted by incorporating emulsifiers.

The overall increase in oil absorption and foaming capacities, together with decreased water absorption, demonstrates superior film-forming properties for modified starch. These alterations indicate that the modified starch will create more stable and lasting edible films, which is critical for improving tomato shelf life (Alimi, 2021). The slightly higher swelling index also indicates flexibility, while the lower emulsion capacity can be mitigated through formulation adjustments.

Mechanical Properties

The compressibility test results of the edible film samples MAG (modified starch, guar gum, gelatin), SGA (native starch, guar gum, gelatin), MSG (modified starch, gelatin) and MSA (modified starch, guar gum) are shown in Table 4 with sample MAG having the highest compressive extension at break, compressive strain at break, compressive strain at maximum compressive extension and modulus. MSG has the highest extension at break and energy at break and MSA has the highest compressive stress at maximum compressive extension, compressive load at maximum compressive extension compressive load at break and compressive stress at break. Extension at break describes how much a material can be stretched or deformed before it breaks. Maximum compressive extension is the maximum amount of deformation a material can sustain under compressive load before failure and energy at break or toughness is the amount of energy required by a material before breaking. This result showed that all the films from modified starch had a higher compressive strength compared to the films from native cassava starch. Crosslinking starch molecules with chemical agents enhances intermolecular bonding among starch chains. These bonds strengthen the network structure of the films from the modified starch, improving its ability to withstand compression without breaking.

Compressive strength is a mechanical property of edible films as well as a parameter that determines the ability to withstand loads. It also affects the ability of the material to with-stand pressure when applied at the maximum limit. High compressive strength is needed for food product packaging to protect them during handling, transportation, and marketing processes (Nazarudin *et al*., 2023). Ulyarti *et al*. (2020) reported that the addition of gelatin in cassava starch-based film increases its compressive strength. Nazarudin *et al*. (2023) studied the mechanical properties of modified

cassava starch-based edible film and reported that it had a higher compressive strength than the native cassava starch.

Table 4: Compressibility Test Result on the Starch-based Edible Film

	MAG	SGA	MSG	MSA
Compressive extension at Break (Standard) (mm)	12.52 ± 0.05^{a}	9.66 ± 0.28^{b}	9.08 ± 0.02^{c}	9.98 ± 0.01^{b}
Compressive strain at Break (Standard) (%)	82.68 ± 0.04^{a}	65.25 ± 0.03^{c}	60.05 ± 0.01^{d}	66.01 ± 0.01^{b}
Compressive load at Break (Standard) (N)	52501.23 ± 0.01^{d}	52509.18 ± 0.01^{b}	52507.27 ± 0.02^{c}	52513.45 ± 0.01^{a}
Compressive stress at Break (Standard) (Mpa)	2659.65 ± 0.01^{d}	2660.09 ± 0.08^{b}	2659.95 ± 0.01^{c}	2660.26 ± 0.01^{a}
Energy at Break (Standard) (J)	92.65 ± 0.02^{d}	95.12 ± 0.08^{c}	108.96 ± 0.02^{a}	97.76 ± 0.15^{b}
Extension at Break (Standard) (mm)	-12.54 ± 0.08^{c}	-9.86 ± 0.01^{b}	-9.04 ± 0.03^{a}	-9.98 ± 0.02^{b}
Compressive load at Maximum Compressive extension (N)	52501.23 ± 0.01 ^{d}	52509.19 ± 0.01 ^{b}	52507.31 ± 0.08 ^{c}	52513.44 ± 0.01 ^{a}
Compressive strain at Maximum Compressive extension (%)	82.72 ± 0.01 ^{a}	65.32 ± 0.06 ^{c}	60.05 ± 0.01 ^{d}	66.01 ± 0.01 ^{b}
Maximum Compressive extension(mm)	12.49 ± 0.01 ^{a}	9.9 ± 0.06 ^{b}	9.07 ± 0.01 ^{c}	9.97 ± 0.01 ^{b}
Compressive stress at Maximum Compressive extension (MPa)	2659.65 ± 0.01 ^{d}	2660.04 ± 0.01 ^{b}	2659.95 ± 0.01 ^{c}	2660.26 ± 0.01 ^{a}
Modulus (Automatic) (MPa)	13608.54 ± 0.02 ^{a}	13273.99 ± 0.01 ^{b}	11905.05 ± 0.01 ^{d}	12567.44 ± 0.08 ^{c}

Results are mean values of duplicate determination ± standard deviation. Mean values within the same column having the same letter are not significantly different at $p<0.05$.
KEYS: MAG=Modified starch, Guar gum, Gelatin; SGA= Native starch, Guar gum, Gelatin; MSG=Modified starch, Gelatin; MSA=Modified starch, Guar gum.

Table 5 shows the tensile test result of edible films made from cassava starch, both native and modified. The final area and final length remain constant across all samples. This uniformity in final area and length assures that discrepancies in other mechanical properties like modulus, tensile strength, and extension at yield are not due to variations in size or shape but rather the result of differences in the composition of the edible films. By keeping the area and length constant, it creates a controlled environment for assessing the mechanical performance of the films, allowing for more valid comparisons between formulations.

Film thickness remained consistent across all treatments (MAG, SGA, MSG, and MSA). This uniform thickness is an important factor in ensuring that the coatings provide comparable coverage over the surface of the tomatoes. A uniform film thickness contributes to even moisture retention and gas exchange regulation, which are critical in extending the shelf life of coated tomatoes. Drying kinetics and film formulation affect film thickness, which may cause differences in film structure (Naeem *et al*., 2018). The thickness of edible films is an important parameter because it affects the biological properties and the shelf life of the coated

food. The effectiveness of edible films and coatings for protection of food depends primarily on controlling the spreading of the coating solutions, which affect the thickness of the film.

Table 5: Tensile Test Result on the Starch-based Edible Film

SAMPLES	MAG	SGA	MSG	MSA
Final area	10.00 ± 0.00^{a}	10.00 ± 0.00^{a}	10.00 ± 0.00^{a}	10.00 ± 0.00^{a}
Final length	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}
Modulus	0.19 ± 0.00^{d}	3.82 ± 0.00^{a}	0.26 ± 0.00^{c}	0.43 ± 0.01^{b}
Load at yield	0.20 ± 0.00^{d}	1.50 ± 0.00^{c}	1.86 ± 0.00^{b}	12.39 ± 0.02^{a}
Extension at yield	7.04 ± 0.00^{c}	16.77 ± 0.62^{b}	16.77 ± 0.63^{b}	52.39 ± 0.05^{a}
Final thickness	1.00 ± 0.00^{a}	1.00 ± 0.00^{a}	1.00 ± 0.00^{a}	1.00 ± 0.00^{a}
Tensile strain at 0% of break	0.14 ± 0.00^{a}	0.03 ± 0.00^{b}	0.01 ± 0.00^{c}	0.01 ± 0.00^{d}
Load at break	1.60 ± 0.00^{b}	0.58 ± 0.00^{c}	0.26 ± 0.00^{d}	2.27 ± 0.00^{a}
Ultimate tensile strength	0.01 ± 0.00^{d}	0.07 ± 0.00^{c}	0.09 ± 0.00^{b}	0.63 ± 0.00^{a}
Tensile stress at yield	9518.09 ± 0.09^{d}	106373.60 ± 1.39^{c}	138053.17 ± 3.17^{b}	1650775.77 ± 5.65^{a}
Tensile strain at break	0.51 ± 0.00^{c}	0.48 ± 0.00^{d}	2.50 ± 0.00^{a}	1.82 ± 0.00^{b}
Tensile strain at yield	0.06 ± 0.00^{d}	0.39 ± 0.00^{c}	0.46 ± 0.00^{b}	1.62 ± 0.00^{a}

All values are mean ± SD of two replicates. Values with the same alphabets across rows are not significantly different ($p<0.05$).
Keys: MAG= Tomato coated with modified starch, guar gum and gelatin, SGA= Tomato coated with Native starch, gelatin and guar gum, MSG= Tomato coated with modified starch and gelatin, MSA= Tomato coated with modified starch and guar gum.

The modulus, which determines the stiffness of the film, varied significantly between the samples. SGA had the highest value (3.82 ± 0.00), followed by MSA (0.43 ± 0.01), MSG (0.26 ± 0.00), and MAG (0.19 ± 0.00)
This indicates that the native starch (SGA) coating generated the stiffest film. The modified starch films (MAG, MSA, and MSG), on the other hand, produced lower modulus values, indicating a more flexible film. For food coatings, greater flexibility is preferred since it enables better adaptation to the tomato's surface without cracking (Kurek, 2019). The extension at yield measures the film's ability to stretch before deformation. MAG had a significantly lower extension (7.04 ± 0.00) compared to MSA (52.39 ± 0.05), suggesting that the modified starch and guar gum (MSA) created the most stretchable and flexible film. This is advantageous for coating applications, where flexibility is critical to prevent the film from cracking as the tomato undergoes changes during ripening (Ghanbarzadeh and Almasi, 2011).

The amount of stress the film can withstand before breaking is indicated by the tensile stress at yield. The results showed a wide range of values, with MSA (1650775.77 ± 5.65 Pa) surpassing the other samples and demonstrating the maximum stress tolerance. On the other hand, the film made from modified starch and guar gum (MSA) exhibited the lowest stress tolerance (9518.09 ± 0.09 Pa), suggesting that it is the most resilient and long-lasting material under stress. Since MSA can withstand more mechanical impacts during handling and storage, it is the perfect covering for protecting tomatoes. The MSA sample had the highest ultimate tensile strength (UTS) of 0.63 ± 0.00 N, suggesting its better strength compared to the other samples. This demonstrates how modified starch and guar gum work together to create a strong film that can bear a higher force before failing, which is essential for preserving the coating's structural integrity during long storage times. According to Liu (2020), the enhanced UTS demonstrates how well starch

modification works to improve the mechanical strength of edible films.

Conclusion

In conclusion, the study revealed that starch modification significantly improved the strength and stability of edible films and extend the shelf life of coated tomato samples by preserving the fruit's nutritional value and reducing spoilage. The flour and films made from modified starches revealed a significant difference ($P<0.05$) in the colour, pasting, antioxidant and mechanical properties of the flour and films.

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