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Optimization of Mechanical, Optical, Barrier and Bioactive Properties of Edible Films from Tomato Puree, Tomato Peels and Moringa Leaf Extract

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Abstract Edible films are desired due to their eco-friendliness, opportunity for active substance delivery, and excellent alternatives to conventional packaging. This study was designed to develop, characterize, and optimize bioactive edible films from tomato puree and peels, and moringa leaves extract. A central composite orthogonal design was used for the formulation of the film-forming solution, comprising of Tomato Peel Fiber (0-10 g/100 g), and Moringa Leaf Extract (0-5 g/100 g). The thickness, mechanical properties, colour indices, water vapor transmission rate, antimicrobial and antioxidant activities of the bioactive films were determined and optimized. The film thickness of the edible films ranged from 0.36-1.42 mm, while the mechanical properties showed tensile strength between 0.289-6.374 N/mm^2, elongation at break (0.502-6.287 mm), stress at break (0.060-5.088 N/mm^2), strain at break (1.67-20.96%), young modulus (19.56-225.08 N/mm^2). Colour parameters were lightness (L* 34.97-58.33), redness, (a* 0.10-4.94), yellowness index, (b* 2.67-20.61), total colour difference, ΔE (17.34-44.63), and whiteness index, WI (34.91-53.32). The WVTR ranged from 0.51-15.50 g/m^2/h, while maximum antimicrobial inhibition zones against *Xanthomonas euvesicatori*a and *Alternaria alternata* were 5.50 and 9.00 mm, respectively. The DPPH radical scavenging power of the edible films ranged from 7.01 – 68.22%. Incorporation of tomato peel fiber and moringa leaf extract enhance mechanical and bioactivity properties of the film.

Keywords: *bioactive films, biodegradable, moringa leaf extract, tomato peels*

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1. Introduction

The search for environmentally friendly and sustainable packaging solutions has accelerated recently, pushing academics and business experts to consider innovative substitutes for conventional packaging materials. Since edible films can improve food preservation and are renewable and biodegradable, they are a promising option made of biopolymers produced from natural sources [1]. However, biopolymer materials from tomato purees have subpar mechanical characteristics, they are sensitive to water, and as a result possess poor resistance to moisture loss from the produce, and reinforcement of the polymer matrix presents a solution to this challenge [2]. In this context, strengthening the polymer matrix can be applied to enhance the physical characteristics of these films. Reinforcement of edible film biopolymers with natural fibers from diverse sources have been reported by many researchers. Due to advantageous properties of natural fibers, such as low cost, recyclability, low density, availability, biodegradability, good mechanical strength, and environmental friendliness with no emission. Researchers have exploited natural fibers by incorporation into biopolymer matrices [3]. Tomato peels is reach in natural fiber with potential to enhance mechanical properties of edible films made from tomato puree. The industrial processing of tomato *(Lycopersicum esculentum*) results in the generation of huge quantity of by-products composed of tomato seed, peels, and small amount of pulp. These by-products are used as livestock feed or thrown away as solid trash [4]. This by-product generated by tomato processing industries is readily available throughout the year, but its use has been confined to serve as compost manure or animal feed. Attempts have been made in the recent past to diversify the applications of tomato peels [5]. Incorporating cellulose fiber from this tomato peels as reinforcement to packaging films and coatings for fresh produce packaging will add to the available methods of utilization and management of tomato processing wastes.

In addition to physical protection from the external environment, research interests have shifted to packaging materials that are bioactive by having antimicrobial and/or antioxidant properties. These groups of packaging materials are termed active or smart for possessing the ability to confer extra protection to foods on transit, by constantly providing an unfavorable environment to spoilage organisms [6]. A couple of food packaging researchers have proposed edible coatings and films that are designed to lag or completely stop the development of microorganisms [6]. The use of moringa leaf extract, which is high in bioactive elements, can improve the film's antimicrobial and antioxidant profiles, in addition to adding functionality [7]. Moringa oleifera had been found through various research to possess antimicrobial and antioxidant properties [8,9]. The characteristics antimicrobial and antioxidant effects of *Moringa oleifera* constituents are responsible for its preservative effects. The bioactivity of Moringa oleifera has been reported to be as result of phenolic compounds and other biochemicals extractable from the essential oil. Since ancient times, oils extracted from plants have been employed, particularly in the fields of food preservation, medicine, alternative cures, and pharmaceuticals [10]. Essential oils are categorized as substances that exist naturally and therefore are safe. Prior investigations revealed that essential oils can shield foods against fungi and bacteria [11].

For the edible films to be functional and long-lasting, mechanical attributes like elasticity, flexibility, and tensile strength must be optimized. Achieving the best possible optical qualities also improves the films' visual attractiveness, which draws in more customers. Examples of these qualities are transparency and color stability [12]. The ability of barrier qualities, especially those related to moisture and oxygen resistance, is essential for maintaining the freshness and quality of packaged food items and increasing their shelf life. This study achieved the development of bioactive edible film from a low-cost biopolymers-tomato puree, peels, and moringa leaf extract, that is biodegradable, and as well possess innate antimicrobial effects, contributing to the overall hurdle technology aimed at ensuring the preservation of quality of packaged products during the physical distribution and handling as well as enhance safety and environmental sustainability.

2. Materials and Methods

Materials

Red matured tomatoes (roma) for puree production were purchased from Ojo market, Ibadan, Oyo State. Moringa leaves were plucked from moringa tree in Bells University, Ota and identified. Other required chemicals were of analytical grade and provided by Food Technology laboratory of University of Ibadan and Bells University of Technology, Ota. The tomato peel fiber was produced from tomato pomace from Tomato Jos Farming and Processing Ltd., Kaduna.

Methods

Tomato puree production

Red matured tomatoes were graded based on external colour in line with USDA standard for classification of tomato colour and defectives fruits were removed. Methods of Chowdhury [13] with slight changes was used to produce tomato puree as shown in Figure 1. Red matured tomatoes were chilled by washing with Running water to lower the field heat. The tomatoes were blanched in hot water (100°C) for 3 minutes, and the skins of the tomatoes were manually removed. The peeled tomatoes were cut into halves and the trapped seeds in the pulps were carefully removed. The separated pulp portion is blended using a SONIK SB-520, Japan blender for 10 minutes. The surplus water was removed using a muslin-cloth on free flow for 10 minutes to obtain tomato puree. The tomato puree was heated to boil for 20 minutes to sterilize it, filled into sterile glass jar, and inverted for 15 minutes, after which it was stored at 0°C in the refrigerator. The brix content of the tomato after processing was 20%.

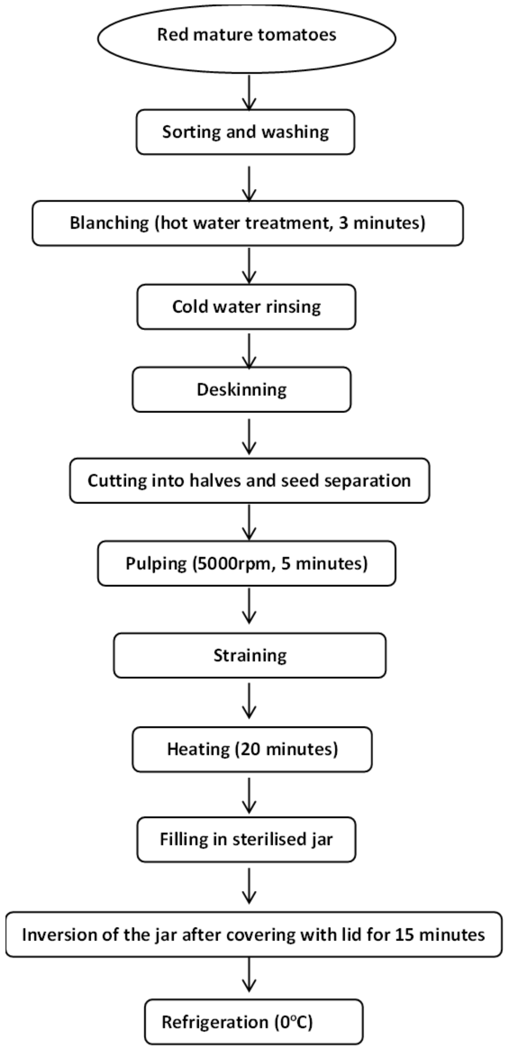

Figure 1. Preparation of tomato puree (18% solid content)

Preparation of tomato peels fiber

Tomato peel fiber was prepared by the methods reported by Donegà [14] with minimal changes. Tomato pomace, consisting of peels and seeds was sampled from Tomato Jos Farming and Processing Limited, Kaduna. A total amount of 5 kg of tomato pomace was collected and stored at 4 °C before preparation. After separating the peels and seeds in a decanter, the peels were centrifuged at 5000 rpm for duration of 2 minutes. After decantation, the recovered peels were dehydrated in an oven (Memmert, UN30) at 65°C for eight hours. The dried peels were ground into a fine fiber powder (<2.5 µm) using a laboratory milling machine. Prepared tomato peel fiber was packed in glass jar and stored at 4°C before use. Figure 2 displays the flowchart for preparation of tomato peel fiber.

Moringa leaf extract preparation

The maceration technique reported by Vongsak [15] was employed for the preparation of moringa leaf extract (MLE). The dried and milled moringa leaves were mixed with 70% analytical grade ethanol at the ratio of 1:4 w/v basis. This mixture was kept at ambient temperature (30 ± 2°C) for 72 hours, with intermittent shaking. After the stand time, the filtration of the mixture was done using Whatman No 4-filter paper. The residue was remixed with the same solvent until the clear solvent is obtained. The moringa leaf extract was subjected to vacuum desiccation using rotary evaporator (BUCHI F-305) at 40°C. The concentrated moringa leaf extract (MLE) was transferred to an air-tight jar and stored in a refrigerator at 0°C until used. Flow chart of production of moringa leaf extract is depicted in Figure 3.

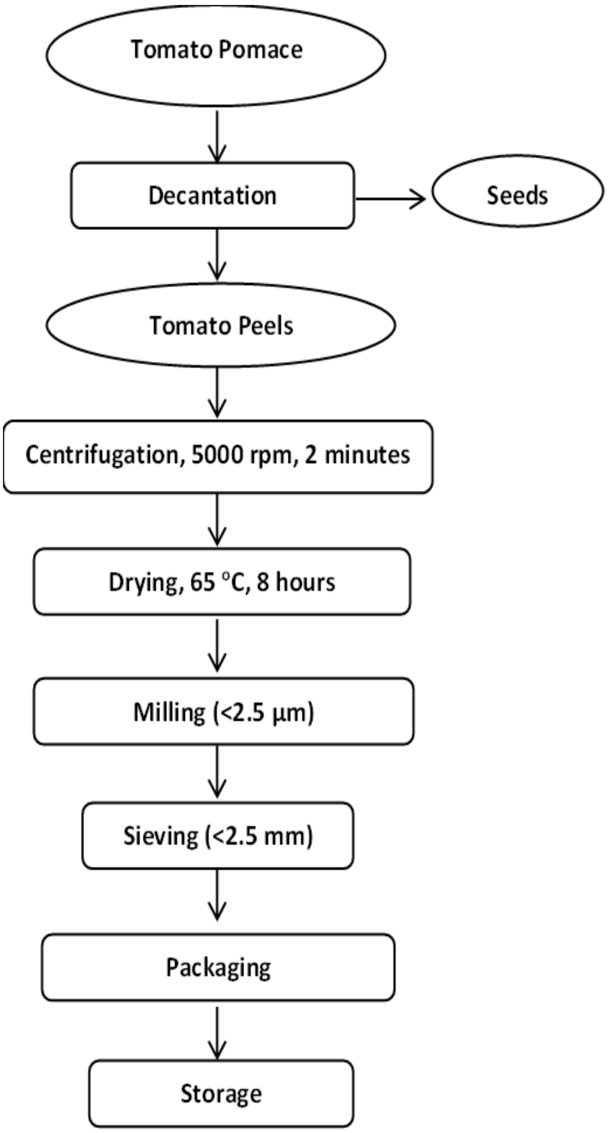

Figure 2. Production of tomato peel fiber

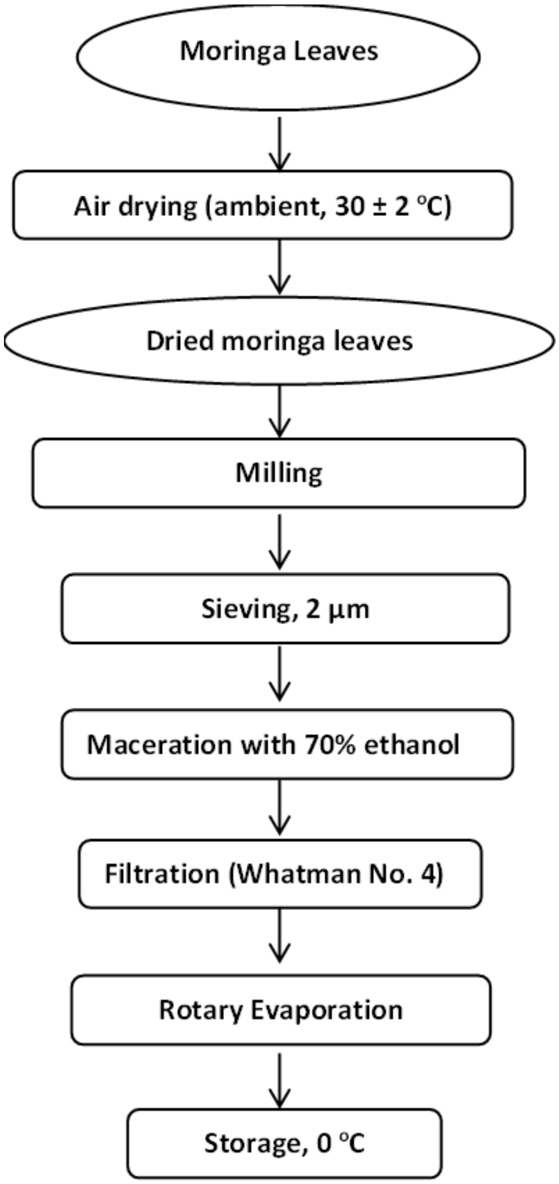

Figure 3. Production of moringa leaf extract

Preparation of films from tomato puree (TP), tomato peels fibers (TPF), and moringa leaf extract (MLE)

Response surface methodology (RSM) was employed for the experimental design for the preparation of the film-forming solutions for the edible films, containing tomato puree (TP), tomato peel fiber (TPF), and moringa leaf extract (MLE). The central composite orthogonal design (CCOD) and optimization for the edible films was done using StatEase Design Expert Software Package version 13.0. The two independent factors of tomato peel fibers and moringa leaf extract were combined at 0-10 and 0-5g/100g tomato puree, respectively. Pectin was added to tomato puree (100 g) as plasticizer, mixed thoroughly before addition of MLE and TPF as shown in Figure 4. The range chosen for this experimental was from preliminary trials on variation that can achieve a stretch film.

The 5-level, 2-factor mixture response surface design was utilized to optimize the edible film's formulation. The impact of two independent variables: tomato peel fiber

(A; 0 - 10 g), Moringa leaf extract (B; 0 - 5g) on the thickness, mechanical properties (tensile strength, elongation at break, stress at break, strain at break and young modulus), colour (*L**, *a**, *b**, total colour, whiteness index), water vapor transmission, antimicrobial activity and antioxidant activity of the tomato puree based edible films was determined. Based on the findings of exploratory tests, the range and center point values of the two independent variables shown in Table 1 were calculated. Five tiers (−α, 1, 0, +1, +α) of coding were used for each variable that needed to be improved. Using alpha level of 1.2671, star points were calculated. Based on CCOD, thirteen randomized trials were generated, with five replicates of the center point.

Briefly, the required amount of tomato peel fiber, and moringa oleifera extract per Run was measured accurately for each Run and added to 100 g tomato puree, contain 3% pectin, and mixed thoroughly for 15 minutes for even distribution of the component in a laboratory magnetic mixer to form the film-forming solutions that were cast into a circular acrylic plate (9 cm), and oven-dried at 50°C for 18 hours. The films were peeled off manually from the plates and stored in a desiccator before further characterization. The second-order polynomial equation was applied to determine the relationship between the independent variables and the outcomes.

$$Y = \beta o + \sum \beta iXi + \sum \beta iiXiXi + \sum\sum \beta ijXiXj \quad (1)$$

Y is the predicted response; β_o is a fixed constant; β_i is the linear coefficient; β_{ij} is the cross-product coefficient; and K is the number of factors [16,17]. Statease design expert software version 13 was applied to determine the coefficients of the second-order polynomial and adequacy of the models for the dependent and independent factors.

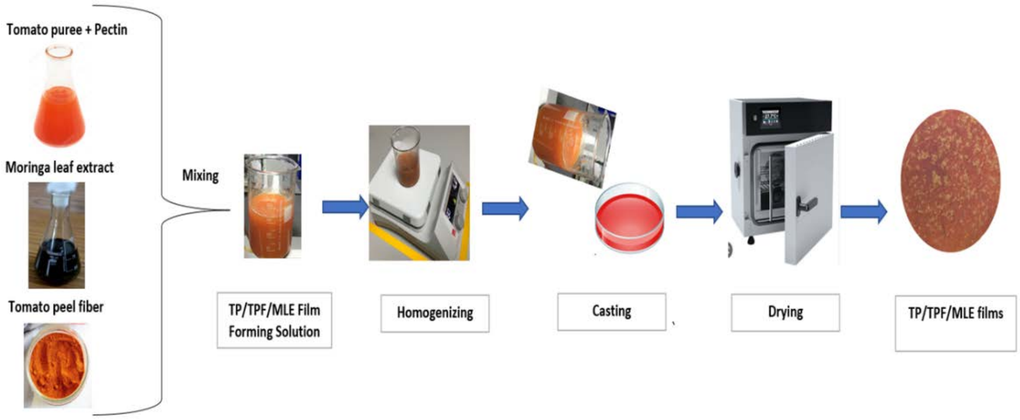

Figure 4. Schematic diagram of production of the edible films

Table 1. Experimental design for levels of incorporations of tomato puree (TP), tomato peel fiber (TPF) and moringa leaf extract (MLE) to produce the edible films

Run	A: Tomato Peel Fiber (g)		B: Moringa oleifera leaf extract (g)		Tomato Puree (g)
	Coded	Uncoded	Coded	Uncoded	Uncoded
1 center	0.00000	5.00	0	2.50	100
2 Axial	0.00000	5.00	-1.2671	0.00	100
3 Axial	-1.26710	0.00	0	2.50	100
4 Axial	1.26710	10.00	0	2.50	100
5 Center	0.00000	5.00	0	2.50	100
6 Axial	0.00000	5.00	1.267103	5.00	100
7 Factorial	-1.00000	1.05	-1	0.53	100
8 Factorial	-1.00000	1.05	1	4.47	100
9 Centre	0.00000	5.00	0	2.50	100
10 Centre	0.00000	5.00	0	2.50	100
11 Factorial	1.00000	8.95	-1	0.53	100
12 Factorial	1.00000	8.95	1	4.47	100
13 Center	0.00000	5.00	0	2.50	100

The method of design optimization

The data from the combination of the factors was subjected to a stepwise multiple regression analyses to relate amounts of tomato peel fiber, and moringa leaf extract to the thickness, mechanical properties (tensile strength, elongation at break, stress at break, strain at break and young modulus), colour parameters (*L**, *a**, *b**, total colour, whiteness index), water vapor transmission, antimicrobial activity, and antioxidant activity of the film samples. The response surface models were generated and shown as three-dimensional plot based on the two ingredients (tomato peel fiber, and moringa leaf extract). In the experiment, the model equation's suitability for forecasting the best response values was examined and the mathematical models were used to establish the ideal composition of the edible films. The regression equations' initial partial derivatives were calculated in accordance with X1 (A) and X2 (B), and they were then sorted to get the ideal values [17].

Determination of film thickness of the edible films

Methods of Chambi and Grosso [18] was employed for the analysis of the thickness of the bioactive composite edible films. A digital micrometer (Mituto, Tokyo, Japan) with a scale of 0 to 25 mm and an accuracy of 0.001 mm was used to measure the thickness of the film. Three measurements were done at random for each analyzed sample, and the values obtained reflected the mean thickness.

Determination of mechanical properties of the edible films

Mechanical properties (tensile strength, elongation at break, stress at break, strain at break and young modulus) were determined with an Texturometer (M500-AT Texture Analyser: Stable Micro Systems, Godalming, UK) observing the recommendations of ASTM D882-9. The films were conditioned prior to measurements in line with ASTM D882-9. The starting grip spacing, and crosshead speed were both set at 30 mm and 5 mm min. ^{1}, respectively. The cut width of the films prior to test was 16.50 mm. For every sample or Run, tests were repeated three times and the average of the results was calculated and reported as mean and standard deviations [19]. The force-deformation profile was plotted automatically from the computer connected to the Texturometer.

Determination of CIE colour parameters (*L**, *a**, *b**) of the films

The CIELAB colour space (*L**, *a**, *b**) measurement system for the films was done with Tri-stimulus Colorimeter (ACCU Probe, HH06). Standard white plate having properties of *L* = 94.62, *a* = 0.91, and *b* = 0.64 served as blank for the calibration of the machine. The film samples were positioned on the standard white plate and mounted at the reflectance port of the colorimeter. Measurement of colour of the edible films was done at random at three different points, with inclusion of the center of the edible films and the *L* a* b** results generated were recorded. The colour difference (ΔE) is a single number that accounts for the variations in the *L**, *a**, *b** values of the edible films, as comparable with standard colour plate and calculated from equation 2. The whiteness index (WI) for the samples was calculated using equation 3. as reported by Pérez-Mateos [20].

$$Total\ Colour(\Delta E) = \left[\begin{array}{l} (Lf_{ilm} - L_{standard})^2 \\ +(a_{film} - a_{standard})^2 \\ +(b_{film} - b_{standard})^2 \end{array} \right]^{0.5} \quad (2)$$

$$Whiteness\ Index\ (WI) = 100 - \left[(100-L)^2 + a^2 + b^2 \right]^{0.5} \quad (3)$$

Determination of water vapour transmission rate of the films

Moisture vapour transfer rate (g/m^2/h) was determined by gravimetric method using modified ASTM 96-00 reported by Singh [21]. To get 100% RH below the film, 15 ml of distilled water were added to the test cup. The edible films were mounted to the cup's rim and fastened and sealed with silicon gum. The setup of edible films mounted on top of the cups were placed in a desiccator containing pre-dehydrated silica gel at 25^{o}C. The silica gels were pre-dried at 180 ^{o}C for 3 hours for this measurement. The entire setup was kept at 25°C and the loss of weight of the test cell was determined after storage for 24 hours. WVTR of the films was determined according to the equation below.

$$WVTR = \Delta W / (\Delta t \times A) \quad (4)$$

ΔW = difference between final and initial weight (g)
Δt = the duration of the experiment (h)
A = the surface area of the edible films (m^2)

Analysis of antimicrobial activities of the edible films

Adopting the methods of Wang [22], the agar diffusion technique was used to assess the edible films' antibacterial and antifungal activity for selected prevailing tomato pathogens. Inoculum of 0.1 mL, 105 - 10^6 cfu/mL of isolated *Xanthomonas euvesicatoria* and *Alternaria alternata* tomato, causative organisms for tomato bacteria spot and black mould respectively were added to the nutrient agar medium and potato dextrose agar (PDA) in a Petri dish, respectively. Using a hole-puncher, the resulting films were divided into discs with a 6 mm diameter, which were then hygienically put on antimicrobial cultures' plates. The incubation took place for 24 hours at 37 °C. The diameter of the zone of inhibition was measured with a caliper. The evaluations were conducted in triplicate.

Analysis of antioxidant activities of the edible films

Using the DPPH (2, 2-diphenyl-1-picrylhydrazyl) free radical scavenging experiment, the antioxidant activity of the film samples was assessed [23]. Briefly, 1 mL of a 1 mM methanolic solution of DPPH ((Merck, Darmstadt, Germany) was combined with 3 mL of the film extract solution. The combination underwent vortexing and a 30-minutes incubation period at room temperature in the dark cupboard. A stable non-radical form of DPPH is produced when the DPPH solution is combined with the sample mixture serving as a hydrogen atom donor, and the violet hue simultaneously changes to pale yellow. Then, at 517 nm, the absorbance was determined using HACH DR 6000 spectrophotometer. The equation below was used to calculate the percentage of DPPH free radical quenching activity.

$$DPPH\ scavenging\ effect(\%) = \frac{Abs.\,of\ control\ of\ DPPH - Abs.\,of\ extract}{Abs.\,of\ control\ of\ DPP} \quad (5)$$

Abs. is absorbance value at 517 nm of the methanolic solution of DPPH and Abs of extract is the absorbance value at 517 nm for the sample extracts. Tests were replicated three times for each sample. The extract concentration at which 50% of the radicals are scavenged by it, or the IC_{50} value, was determined using linear regression after the DPPH's scavenging activity was plotted versus concentration.

Determination of light transmission rate of the optimized films

The method outlined by Song *et al*., [24] for determining light transmittance of edible films was applied. Cuvettes were fitted with films that were cut into rectangular shape of 5 cm x 2 cm. To investigate the effectiveness of edible films as a barrier against UV and visible light, a spectrophotometer (HACH DR 6000) was used to measure the transmittance of the films using triplicate samples at wavelengths ranging from 200 to 800 nm. As a baseline for comparison with the edible films, a cuvette that was empty was employed.

Determination of film biodegradability test under soil environment

With slight changes, the soil burial technique of Karnnet *et al*. [25] was used to examine the biodegradability of the generated composite films. The finest edible film samples (2 cm^2) were dried in a desiccator until their weights were consistent known as "initial weight". Afterward, 100 g of soil was used to bury the samples, and for five, ten, fifteen, and twenty days straight, weight changes were noted at each interval. Each sample was dried until it reached its ultimate weight, which was then measured. The following calculation was applied to compute the percent weight loss (W%).

$$Weightloss(W\%) = \frac{Initialweight - finalweight \times 100}{Initialweight} \quad (6)$$

Morphological analysis using scanning electron microscopy (SEM)

To study the structural morphology of the biodegradable films produced from tomato puree, tomato peel fiber and moringa leaf extract, the best performing films were subjected to scanning electron microscopy. The methods of Tarique *et al*., [26] was used for analysis of SEM of the edible films. The films were sputtered with gold after being glued, the conductive carbon tape attached them on substrates. The fabricated TP/TPF/MLE samples were scanned using a field emission scanning electron microscope at a 5 mm working distance and 5-kV accelerating voltage.

Statistical analysis

Experimental design and optimization for the edible films was done using StatEase Design Expert Software Package version 13.0. The validity of the developed models was evaluated based on ANOVA, R^2 and Adj-R^2 generated from the software. Descriptive analysis, test of homogeneity, analysis of variance (ANOVA), multiple comparison and homogeneous subsets (turkey test) were evaluated using IBM SPSS statistics, version 23 at significant levels set of $P \leq 0.05$.

Table 2. Mechanical properties of the tomato puree, tomato peel fiber and moringa leaf extract films

Run	Tomato peel fiber (g/100g)	Moringa leaf extract (g/100g)	Film thickness (mm)	Tensile Strength (N/mm^2)	Elongation at break (mm)	Stress at break (N/mm^2)	Strain at break (%)	Young modulus (N/mm^2)
1	5.00	2.50	0.940 ± 0.056^{b}	1.461 ± 0.256^{d}	1.544 ± 0.220^{abc}	1.813 ± 0.291^{b}	5.146±0.764abc	103.783 ± 16.303^{cde}
2	5.00	0.00	0.850 ± 0.040^{b}	1.824 ± 0.121^{bcd}	0.957 ± 0.259^{ab}	0.509 ± 0.098^{ab}	3.189 ± 0.865^{ab}	109.504 ± 20.894^{de}
3	0.00	2.50	0.367 ± 0.035^{a}	5.617 ± 0.115^{e}	6.287 ± 0.603^{d}	4.088 ± 0.330^{c}	20.958±2.009	47.345 ± 3.537^{a}
4	10.00	2.50	1.367 ± 0051^{c}	0.624 ± 0.347^{a}	0.834 ± 0.170^{ab}	0.313 ± 0.422^{a}	2.779 ± 0.567^{ab}	40.531 ± 15.361^{a}
5	5.00	2.50	0.983 ± 0.110^{b}	1.188 ± 0.250^{abc}	1.212 ± 0.102^{abc}	0.152 ± 0.094^{a}	4.040 ± 0.3415^{bc}	70.022 ± 14.20^{abcde}
6	5.00	5.00	0.903 ± 0.042^{b}	2.133 ± 0.247^{cd}	1.803 ± 0.207^{bc}	1.175 ± 0.571^{ab}	6.011 ± 0.691^{bc}	98.637 ± 7.075^{bcde}
7	1.05	0.53	0.360 ± 0.000^{a}	6.374 ± 0.264^{ae}	2.226 ± 1.464^{c}	5.088 ± 1.464^{c}	7.421 ± 0.697^{c}	225.082 ± 14.013^{f}
8	1.05	4.47	0.353 ± 0.049^{a}	4.337 ± 0.356^{ae}	5.136 ± 1.071^{d}	1.587 ± 0.218^{ab}	13.062±3.571	118.136 ± 18.923^{e}
9	5.00	2.50	0.887 ± 0.045^{b}	1.141 ± 0.234^{abc}	1.247 ± 0.278^{abc}	0.271 ± 0.019^{a}	4.157 ± 0.925^{abc}	64.421 ± 17.063^{abcd}
10	5.00	2.50	0.903 ± 0.015^{b}	0.854 ± 0.333^{ab}	1.326 ± 0.316^{abc}	0.0187 ± 0.058^{a}	4.420 ± 1.054^{abc}	51.337 ± 22.844^{ab}
11	8.95	0.53	0.880 ± 0.098^{b}	0.617 ± 0.302^{a}	0.502 ± 0.047^{a}	0.344 ± 0.453^{a}	1.673 ± 0.158^{a}	56.004 ± 33.383^{abc}
12	8.95	4.47	1.420 ± 0.050^{c}	0.289 ± 0.038^{a}	0.720 ± 0.072^{ab}	0.060 ± 0.050^{a}	2.399 ± 0.239^{ab}	19.556 ± 4.012^{a}
13	5.00	2.50	1.013 ± 0.040^{b}	1.120 ± 0.148^{abc}	1.638 ± 0.183^{abc}	0.387 ± 0.111^{ab}	5.459 ± 0.611^{abc}	64.799 ± 10.96^{abcd}

Values are the mean of the triplicate analysis + standard deviation (n =3). Values with different superscripts letter along the same column are significantly different ($P \leq 0.05$) using Turkey Test.

3. Results and Discussion

Effects of independent variable on the thickness of the films

The effects of independent variables on the thickness of the edible films are presented in Table 2. From the results obtained, the thickness of the edible films ranged from 0.36 mm to 1.42 mm. The highest value for film thickness was obtained for Run 12 comprising 8.95 g/100g of TPF and 4.47 g/ 100g of MLE, while Run 3 made of 0 g/100g of TPF and 2.50 g/100 of MLE had the lowest value. The thickness of TP/TPF/MLE edible films was positively related to TPF and MLE concentrations

($p \leq 0.05$). The results obtained for TP/TPF/MLE edible films were similar with figures reported by Torres-León *et. al*., [27] for edible films made from mango by-products, which effectively improved the gas transmission rate of peach coated with it. Contrarily, Chambi and Grosso, [18] in their findings reported lower thickness for biodegradables films based on methylcellulose, glucomannan, pectin and gelatin. Furthermore, the thickness obtained was higher than values of 0.25 mm set by Japanese Industrial Standards for edible films [28]. This could be as result of low bulk density of the tomato peel fiber utilized in the fabrication.

The three-dimensional surface plot of the thickness of the edible films (A: tomato peel fiber versus B: moringa leaf extract) is shown in Figure 5.

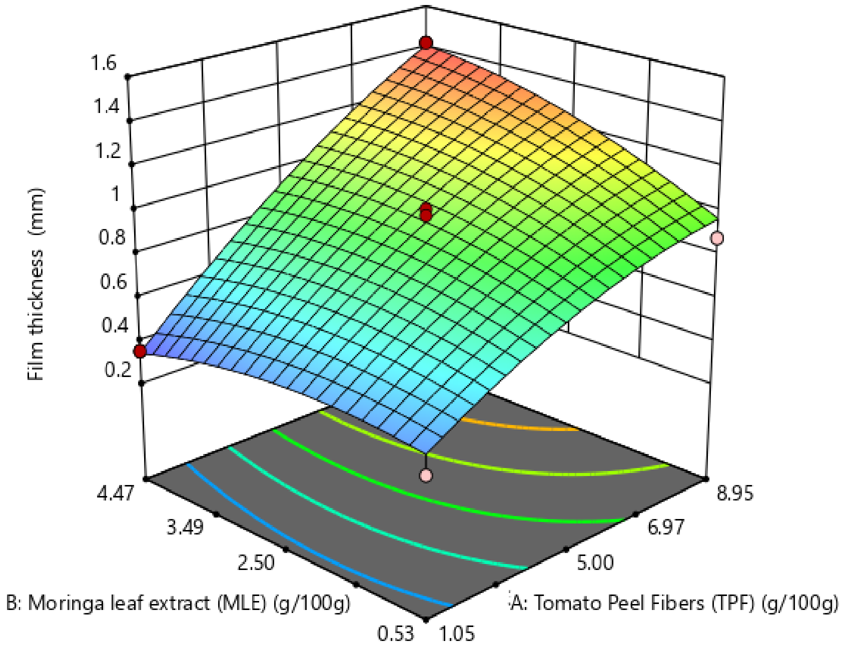

Figure 5. Response surface plot of effects of TPF and MLE on thickness of edible films

The plot revealed that thickness of TF/TPF/MLE edible films increases with increase in concentration of tomato peel fiber and marginally decreased with increase in moringa leaf extract. This could be due to lower bulk density of tomato peel fiber, when compared to moringa leaf extract.

The relationships between the independent variable (tomato peel fiber and moringa leaf extract) and the thickness of the films (dependent variable) are shown in linear equation 7. The equation 6 below shows that both tomato peel fiber and moringa leaf extract had quadratic effects. Also, the interaction between the independent variables was positive for both tomato peel fiber and moringa leaf extract.

$$\begin{aligned} \mathit{Film\ Thickness} &= +0.307041 + 0.109959 * TPF \\ &+0.053897 * MLE + 0.017565 * TPF * MLE \\ &-0.005357 TPF^2 - 0.019908 MLE^2 \end{aligned} \quad (7)$$

The analysis of variance (ANOVA) showed significant effects of tomato peel fiber and moringa leaf extract on the thickness of TP/TP/MO films. Also, there was no lack of fit relative to pure error for the models as shown in Table 5. Singh *et al*., [21] reported quadratic effects on thickness of chitosan-based edible films. Also, similar result was obtained for pea starch- chitosan novel edible films, as the ingredients has quadratic effects, Thakur *et al*., [29]. Similarly, Saberi *et al*., [30] reported quadratic effects of pea starch and guar gum on the thickness of their composite films.

Effects of independent variable on the tensile strength of the edible films

Tensile strength of TP/TPF/MLE edible films is presented in Table 2. The tensile strength of the samples ranged between 0.289 to 6.374 N/mm^2. Edible film (Run 6) made from tomato peel fiber (1.05 g/100g) and moringa leaf extract (0.53 g/100g) had the highest tensile strength (6.374 N/mm^2). The test of tensile strength is crucial to determine stress-strain behavior of edible films, in relation to their suitability as packaging materials. This gives hint on the eventual maximum stress that the edible films can withstand during applications and handling. Sandeep *et al*., [31], reported higher tensile strength for edible films produced from modified cellulose fiber reinforced with PVA. On the other hand, the results TP/TPF/MLE films compared well with that obtained by Du *et al*., [32], who reported tensile strength of tomato films, laced with allspice, garlic, and oregano essential oils. Comparing with Japanese Industrial Standard, the average tensile strength (2.121 N/mm^2) of the developed edible films meet the criteria of greater than 0.39 MPa required for acceptable packaging films [28].

The 3D model graphs of the effects of tomato peel fiber and moringa leaf extract on the tensile strengths of the biodegradable films is shown in Figure 6. Tensile strength of the TP/TPF/MLE films is negatively correlated to the tomato peel fiber amount and with the concentration of moringa leaf extract. Thus, increase in tomato peel fiber and moringa leaf extract reduced tensile strength of the films.

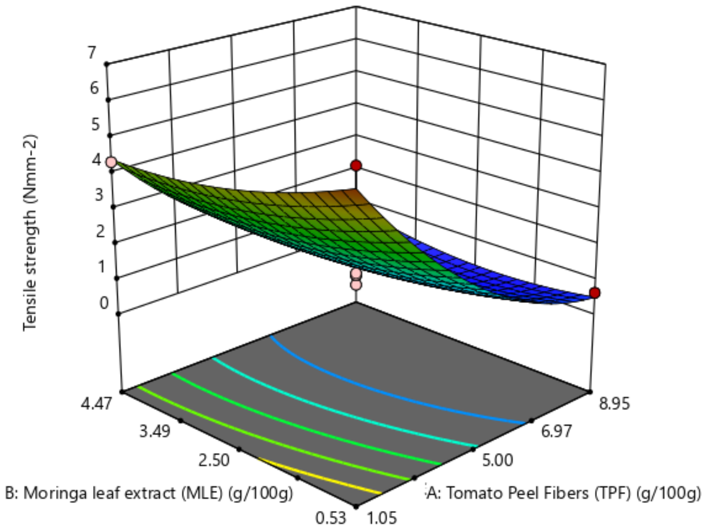

Figure 6. Response surface plot of effects of TPF and MLE on tensile strength of edible films

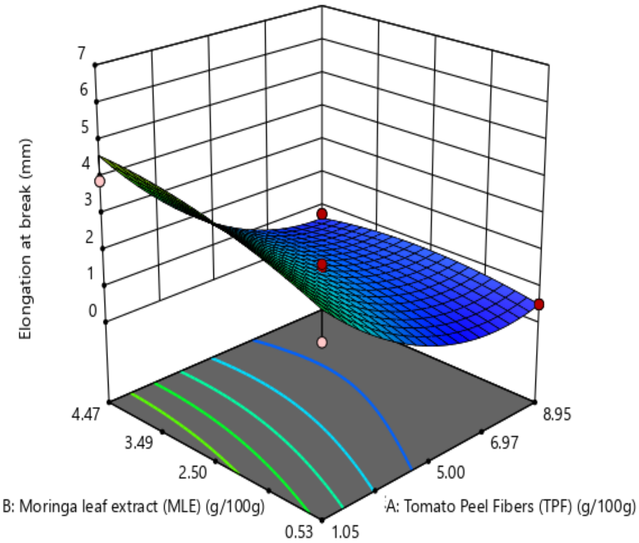

Figure 7. Response plot of effects of TPF and MLE on stress at break of the edible films

The model equation for the interaction between tomato peel fibers and moringa leaf extract shows quadratic effects for tensile strength (Equation 8). Both TPF and MLE has negative effects on the overall equation. The cross-interactions between TPF and MLE as well as individual interaction of TPF and MLE had negative quadratic effects.

$$\begin{aligned} &Tensile\ Strength = +7.67692 - 1.42495 * TPF \\ &-0.941166 * MLE + 0.054878 * TPF * MLE \\ &+0.072083 * TPF^2 + 0.105614 * MLE^2 \end{aligned} \quad (8)$$

The variance analysis (ANOVA) for the model conveyed that it is significant ($P \leq 0.05$) to describe the relationship between TPF and MLE as regard tensile strength of the biodegradable films ($P \leq 0.05$) as shown in Table 5. In order words, the date obtained from the experience could be account for at 93.85% level of accuracy. The findings were like that reported by Nazmi and Sarbon, [12], who observed that quadratic effects of chicken gelatin film blended with carboxyl methyl cellulose on tensile strength.

Effects of independent variable on the elongation at break of the films

Table 2 shows the results obtained for elongation at break (fracture strain) of the TP/TPF/MLE edible films. The elongation at break of different combinations of TP/TPF/MLE ranged between 0.502 to 6.287 mm. The maximum elongation at break was obtained for edible film with 0.00 g/100g of TPF and 2.50 g/100g of MLE, while the lowest elongation at break was recorded for film made from 8.95 g/100g of TPF and 0.53 g/100g of MLE. Elongation at break, also known as fracture strain, demonstrates how a polymer used in packing can tolerate form changes without cracking. Sariningsih *et al*., [33] reported a fabricated edible film from ginger starch, chitosan, and glycerin with elongation at break of higher than that of TP/TPF/MLE. The research posited that increase in chitosan in the formulation resulted to increase in elongation at break. Also, Du *et al*., [32] reported similar elongation at break for edible films made from tomato puree, allspice, garlic, and oregano essential oils. Comparing with Japanese Industrial Standard, the elongation at break of the developed edible films does not meet the criteria of minimum of 70% required for acceptable packaging films [28].

The effects of tomato peel fiber and moringa leaf extract on elongation at break of the films is depicted in 3D surface plot in Figure 7. From the 3D model graphs, increase in tomato peel fibers resulted to reduction of elongation at break, as the edible films become more brittle and fragile. Also, opposite pattern is seen for moringa leaf extract as increase in moringa leaf extract resulted to increase in elongation at break.

Equation 9 below shows the mathematical relationship of the effects of tomato peel fiber and moringa leaf extract on the elongation at break (fracture strain) of the edible films.

$$\begin{aligned} &Elongation\ at\ break = +3.58681 - 0.966110 * TPF \\ &+0.853504 * MLE - 0.047364 * TPF * MLE \\ &+0.066869 * TPF^2 - 0.081405 * MLE^2 \end{aligned} \quad (9)$$

From the model equation, TPF had negative linear effects and positive quadratic effects on the elongation at break. On the other hand, MLE showed positive linear and negative quadratic effects. The cross-product interactions of both TPF and MLE on the elongation at break of the films reveals negative impacts.

Analysis of variance (ANOVA) for the model showed that it is significant ($P \leq 0.05$) to describe the relationship between TPF and MLE as regard elongation at break of the biodegradable films ($P \leq 0.05$). Insignificant lack of fit was obtained for the regression model of the elongation at break as affected by tomato peel fiber and moringa leaf extract. The findings from this experiment compared well with result obtained by Thakur *et al*., [29] who reported elongation at break of 3.4 – 10.5 mm for pea starch-chitosan novel edible films. Also, there was quadratic effects of pea starch-chitosan on the elongation at break for the developed edible films. Also, Jancy *et al*., [34] reported quadratic effects of cellulose nanoparticles synthesised from jack fruit non-edible part on the elongation at break of the fabricated packaging films.

Effects of independent variable on the stress at break of the edible films

The values obtained for the stress at break for the TP/TPF/MLE films is presented in Table 2. From the results, stress at break of the films varied from 0.06 to 5.088 N/mm^2 with the film containing 1.05 g/100g of TP and 0.53 g/100g of MLE having the highest elongation at break. Conversely, the lowest stress at break was achieved for edible films containing 8.95 g/100g of TP and 4.47 g/100g of MLE. Stress at the break is an important material parameter which defines the maximum force a material can withstand when applied to cross-sectional area of the material, beyond which the material would fracture or break. The unit of stress at break is N/mm^2 because it is referenced to cross-sectional area of a material. Famá *et al*., [35] evaluated the effects of sorbate on the stress at break of the edible films made from tapioca-starch. The research reported stress at break of within range for films with and without sorbate. Also, in another study, Bizymis *et al*., [36] reported similar values for stress at break for chitosan-based edible films laced with cellulose nanocrystals and beta-cyclodextrin.

The 3D surface plot shown in Figure 8 respectively shows the interaction between TPF and MLE as independent variables affecting stress at break of the edible films. From the 3D plot, stress at break is negatively related to TPF and MLE in linear terms. Increase in TPF and MLE results to a reduction in stress at break.

Mathematical relationship of the effects of tomato peel fiber and moringa leaf extract on stress at break of the edible films is shown in equation 10 below.

$$\begin{aligned} &Stress\ at\ break = -6.25917 - 1.31189 * TPF \\ &-0.966740 * MLE + 0.103301 * TPF * MLE \\ &+0.066516 * TPF^2 + 0.048703 * MLE^2 \end{aligned} \quad (10)$$

Equation 9 reveals a quadratic interaction between tomato peel fibers and moringa leaf extract as they affect the stress at break of the edible films. While there was negative linear cross-interactions between TPF and MLE as shown from the model equation, positive quadratic interaction exists for both factors affecting stress at break of the edible films.

Analysis of variance (ANOVA) for the model showed that it is significant ($P \leq 0.05$) to describe the relationship between TPF and MLE as regard to stress at break of the biodegradable films ($P \leq 0.05$). Also, insignificant lack of fit was detected relative to pure error. Fairley *et al*., [37] reported that stress at break of edible films made from whey protein isolate and N-ethylmaleimide or cysteine ranged from 5.9 to 7.8 MPa.

Effects of independent variable on the strain at break of the edible films

The strain at break of the biodegradable edible films produced from tomato puree, tomato peel fiber and moringa leaf extract is presented in Table 2. The strain at break recorded for the films was between 1.673 and 20.958%. 11th Run comprising 8.95 g/100g of tomato peel fiber and 0.53 g/100g of moringa leaf extract had the lowest strain at break, while Run 3 with 0 g/100g tomato peel fiber and 2.5g/100g moringa leaf extract recorded the highest values.

Famá *et al*., [35] evaluated the effects of sorbate on the strain at break of the edible films made from tapioca-starch. The research reported higher strain at break for films produced with and without sorbate comparable to TP/TPF/MLE edible films. However, Ekrami and Emam-Djomeh, [38] reported strain at break for edible film made from salep to be within range of values obtained for TP/TPF/MLE edible films.

The 3D model graphs of the effects of tomato peel fiber and moringa leaf extract on the strain at break of the biodegradable films is presented in Figure 9. Strain at break of the TP/TPF/MLE films is inversely proportional to the tomato peel fiber and directly proportional to moringa leaf extract concentration. Thus, increase in both tomato peel fiber resulted to a decrease in strain at break and vice versa for moringa leaf extract.

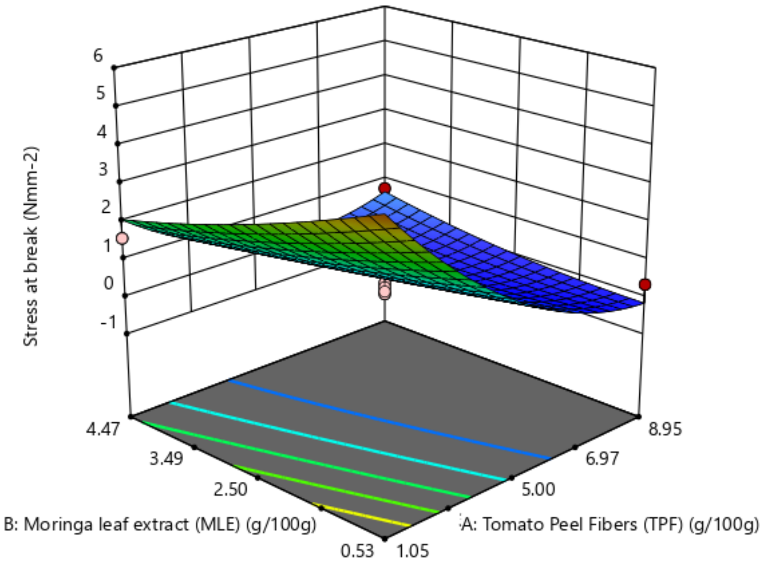

Figure 8. Response plot of effects of TPF and MLE on strain at break of the edible films

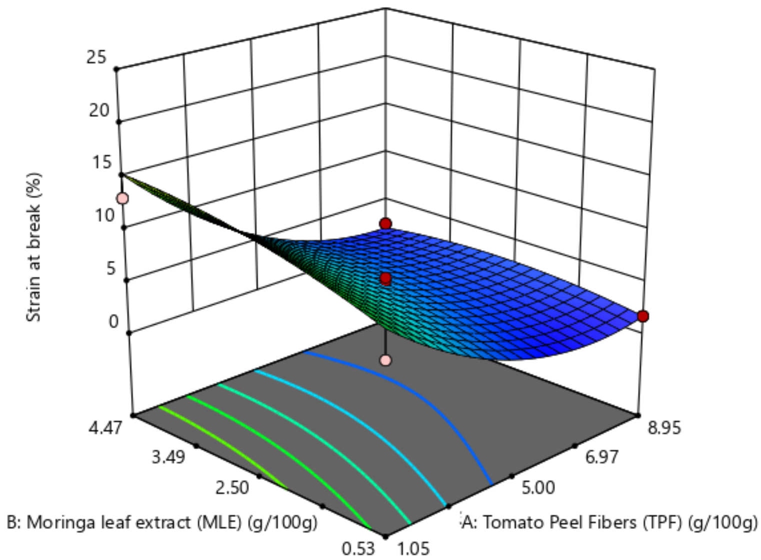

Figure 9. Response plot of effects of TPF and MLE on strain at break of the edible films

$$\begin{aligned} \textit{Strain at break} &= +11.95729 - 3.22068 * TPF \\ &+2.84476 * MLE - 0.157826 * TPF * MLE \\ &+0.222900 * TPF^2 - 0.271359 * MLE^2 \end{aligned} \quad (11)$$

The model equation for the interaction between tomato peel fibers and moringa leaf extract shows quadratic effects for strain at break (Equation 11). While linear effects of TPF is negative and linear effects of MLE is positive. The cross-product interaction between TPF and MLE had negative effective while quadratic relationship of the two-factor had positive and negative effects.

Analysis of variance (ANOVA) for the model showed that it is significant ($P \leq 0.05$) to describe the relationship between TPF and MLE as regard strain at break of the biodegradable films ($P \leq 0.01$) as shown in Table 5. Also. Significant lack of fit was recorded relative to pure error.

Effects of independent variable on the young's modulus of the edible films

Elastic young modulus characterized the intrinsic stiffness of the film. Table 2 shows the effects of independent factors - tomato peel fiber (TPF) and moringa leaf extract (MLE)) on young modulus of the biodegradable films. According to the results obtained, the young modulus of the edible films was between 19.556 and 225.082 N/mm^2. While the Run 12 with 8.95 g/100g of TPF and 4.47 g/100g of MLE had the lowest score on young modulus, Run 7 with 1.05 g/100g of TPF and 0.53 g/100g of MLE posted the highest result for young modulus. Other authors reported similar behavior for edible films made from tomatoes. Du *et al*., [39] reported elastic modulus of within the range of values obtained for edible films produced from tomatoes and carvacrol. In a similar research, Du *et al*., [32] reported that edible films produced from tomatoes, allspice, garlic, and oregano essential oils, had elastic modulus of 44.80 to 68.70 MPa. Comparing with Japanese Industrial Standard, the results of young modulus (19.556 – 225.082 N/mm^2) of the developed edible films meet the criteria of $\geq$ 0.35 MPa required for acceptable packaging films.

The effects of interaction of various levels of incorporation of TPF and MLE on the young modulus of the films is shown in 3D surface response plot shown in Figure 10 below. From the plot, the incorporation of TPF and MLE resulted to decrease in young modus of tomato puree-based films. Therefore, increase in TPF and MLE led to reduction in young modulus of the edible films and vice versa.

$$\begin{aligned} &Youngmodulus \\ &= +158.40778 - 9.70977 * TPF \\ &-11.04644 * MLE \end{aligned} \tag{12}$$

Equation 12 represent the model for the interaction between TPF and MLE to affect the young modulus of the fabricated films. The model equation reveals a linear interaction between tomato peel fibers and moringa leaf extract on the young modulus of the films. The linear interaction of TPF and MLE are both negative, leading to overall conclusion that incorporation of TPF and MLE had overall negative effects on the young modulus of the tomato-based films.

Analysis of variance (ANOVA) for the model showed that it is significant to describe the relationship between TPF and MLE as regard strain at young modulus of the biodegradable films ($P \leq 0.05$). Singh *et al.*, [21] reported quadratic effects on young modulus of chitosan-based edible films. Also, similar result was obtained for pea starch-chitosan novel edible films, as the ingredients has quadratic effects [29]. Similarly, Saberi, *et al.*, [30] reported quadratic effects of pea starch and guar gum on the young modulus of their composite films. In another work, Azeredo *et al.*, [40] fabricated edible films from mango puree reinforced with cellulose nanofibers which had young modulus between 19.85±0.51 MPa and 322.05 ± 19.43 MPa for films with 0g/100g and 36g/100g, respectively.

Effects of independent variable on the Lightness (*L) parameter of the edible films**

The effects of tomato puree, peel fiber and moringa leaf extract on the lightness (*L**) parameter of the edible films is presented in Table 3. The results obtained ranged between 34.97 to 58.33. The sample Run 8 had the lowest value, while Run 4 had the highest lightness parameter. In other research by other authors, lightness (*L**) of edible films made from *acha* starch film ASF, and *iburu* starch film (ISF)ISF where within range of values obtained for TP/TPF/MLE edible films [41]. On the other hand, Galus and Kadzińska, [42] reported higher values for *L** for whey protein-based edible films incorporated with rapeseed oil. Also, the findings from this research compared significantly by results reported by Singh *et al.*, [21] for chitosan-based edible films.

The 3D response plot for lightness as affected by levels of tomato peel fiber and moringa leaf extract is shown in Figure 11. From the plot, increase in tomato peel fiber resulted to rise in lightness of the edible films. On the other hand, increase in the levels of incorporation of moringa leaf extract caused a decrease in the lightness parameters of the films. This is true as moringa leaf extract is dark and would diminish the lightness of the films, unlike tomato peel fiber with tendency toward whiteness.

The model equation showing the relationship between lightness and the levels of incorporation of tomato peel fiber and moringa leaf extract is shown in equation 13.

$$L^* = +46.49 + 9.10 * TPF - 0.4437 * MLE \tag{13}$$

From the equation, the model equation showing the effects of independent variable on the depended variables is linear. In terms of the contribution of the model terms, tomato peel fiber had positive effects, while moringa leaf extract showed a negative interaction on the lightness.
The test of variance revealed that the terms from the model were significant and adequately fitted at ($P \leq 0.05$). The result from ANOVA implied that the linear model terms of tomato peel fiber and moringa leaf extract significant impact the lightness of the tomato-based edible films ($P \leq 0.05$). In contrary pattern, Singh *et al.*, [21] reported that relationship between lightness (dependent variable) and independent variables (chitosan and glycerol) was quadratic.

Table 3. Optical and barrier properties of tomato puree, tomato peel fiber and moringa leaf extract edible films

Sample	Tomato peel fiber (g/100g)	Moringa leaf extract (g/100g)	*L** (Lightness)	*a** (Redness)	*b** (Blueness)	Total colour difference (ΛE)	Whiteness Index	Water vapour transmission rate ($g\ h^{-1}\ m^{-2}$)
1	5.00	2.50	39.9867 ± 0.833^{bc}	1.7300 ± 0.2629^{cde}	15.0600 ± 3.0788^{de}	$26.0033+0.9074^{c}$	38.1017 ± 0.0560^{b}	6.62 ± 0.05^{c}
2	5.00	0.00	49.0467 ± 0.8650^{d}	4.9400 ± 0.1510^{g}	16.7133 ± 0.1779^{def}	34.6133 ± 0.8021^{d}	46.1485 ± 0.0140^{d}	4.98 ± 0.03^{d}
3	0.00	2.50	36.8800 ± 0.2762^{ab}	2.6267 ± 0.0379^{f}	4.6433 ± 0.0451^{ab}	19.2033 ± 0.2818^{ab}	36.6550 ± 0.5299^{ab}	1.38 ± 0.25^{ab}
4	10.00	2.50	58.3333 ± 0.4777^{e}	4.2700 ± 0.0624^{g}	20.6100 ± 0.2022^{g}	44.6267±0.3495	53.3190 ± 0.091^{e}	14.36 ± 0.31^{f}
5	5.00	2.50	42.0800±0.7370c	2.1100 ± 0.7370^{def}	11.0900 ± 0.1646^{c}	25.9633 ± 0.6300^{c}	40.9901 ± 0.0543^{c}	6.57 ± 0.12^{c}
6	5.00	5.00	47.9633 ± 0.2892^{d}	0.1000 ± 0.2892^{a}	13.6100 ± 0.0436^{cd}	32.5033 ± 0.2532^{d}	46.2129 ± 0.0234^{d}	7.70 ± 0.71^{d}
7	1.05	0.53	38.6200 ± 0.2425^{b}	4.4467 ± 0.2425^{g}	7.4967 ± 0.0306^{b}	21.5267 ± 0.2274^{b}	38.0042 ± 0.1220^{b}	1.26 ± 0.02^{b}
8	1.05	4.47	34.9700 ± 0.0721^{a}	0.5267 ± 0.0721^{ab}	2.6667 ± 0.0115^{a}	17.3400 ± 0.0721^{a}	34.9132 ± 0.2340^{a}	$2.90\pm.02^{a}$
9	5.00	2.50	46.5633 ± 0.6519^{d}	1.2133 ± 0.0513^{bc}	13.9467 ± 0.1882^{cd}	31.2267 ± 0.5052^{d}	44.7600 ± 0.0102^{d}	6.70 ± 0.01^{d}
10	5.00	2.50	49.0967 ± 0.6150^{d}	1.3867 ± 0.0757^{cd}	14.8033 ± 0.2367^{de}	33.8900 ± 0.4822^{d}	46.9697 ± 0.9200^{d}	6.66 ± 0.12^{d}
11	8.95	0.53	55.1033 ± 3.6865^{e}	2.3000 ± 0.9619^{ef}	17.7567 ± 2.7870^{efg}	40.6133 ± 0.4976^{e}	51.6647 ± 0.0760^{e}	10.97 ± 0.71^{e}
12	8.95	4.47	56.9267 ± 0.0907^{e}	2.7933 ± 0.0379^{f}	19.4233 ± 0.0252^{fg}	42.8500 ± 0.0819^{ef}	52.6673 ± 0.0330^{e}	13.70 ± 0.03^{ef}
13	5.00	2.50	48.7367 ± 0.4637^{d}	1.3533 ± 0.0416^{bcd}	14.8167 ± 0.0723^{de}	33.5667 ± 0.4015^{d}	46.6212 ± 0.0442^{d}	6.49 ± 0.43^{d}

Values are the mean of the triplicate analysis + standard deviation (n =3). Values with different superscripts letter along the same column are significantly different ($P \leq 0.05$) using Turkey Test.

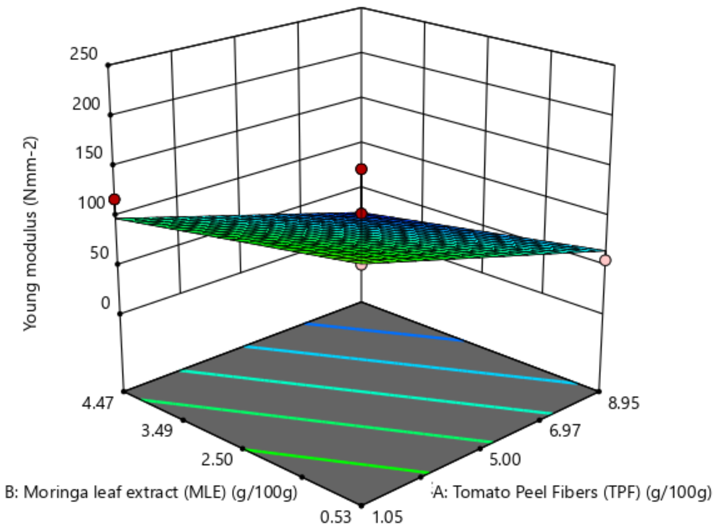

Figure 10. Response plot of effects of TPF and MLE on young modulus of the edible films

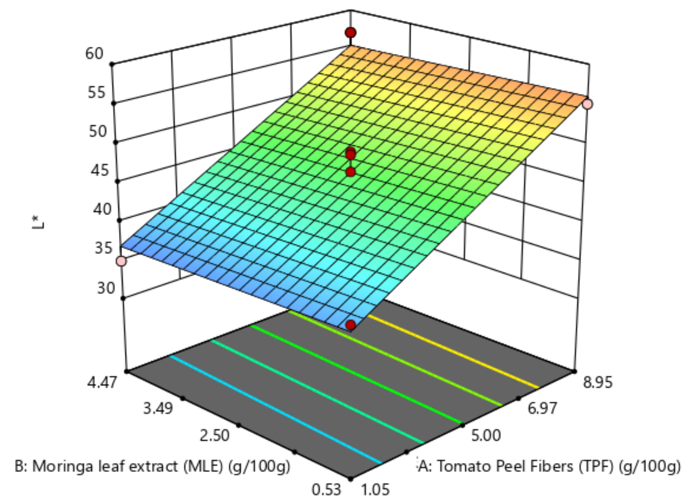

Figure 11. Response plot of effects of TPF and MLE on lightness (*L**) of the edible films

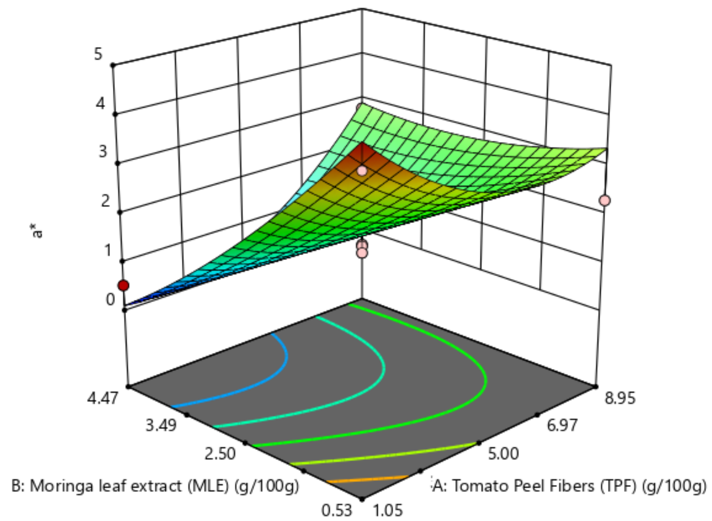

Figure 12. Response plot of effects of TPF and MLE on redness-greenness index (a) of the edible films

Effects of independent variable on the Redness-greenness (*a) parameter of edible films**

The data presented in Table 3 showed that redness-greenness of TP/TPF/MLE edible films was positively related to TPF and MLE concentration ($p \leq 0.05$). From the results obtained, the redness-greenness of TP/TPF/MLE films ranged from 0.10 to 4.94. The highest value for redness-greenness was obtained for Run 2 comprising 5 g/100g of TPF and 2.5g/ 100g MLE, while Run 6 had the lowest value. The redness-greenness of the

TP/TPF/MLE films obtained are comparable to the values obtained for biodegradable films made from fruits and vegetable residue flour reported in similar research. Alimi *et al*., [41] reported *a** values within range for edible films made from *acha* starch and *iburu* starch. Also, Galus and Kadzińska, [42] reported that edible films made from whey protein and laced with rapeseed had redness-greenness within the range reported in this research.

The three-dimensional surface plot of the thickness of the edible films (A: tomato peel fiber versus B: moringa leaf extract) is shown in Figure 12. The plot revealed that redness-greenness of TF/TPF/MLE edible films decreases with increase in concentration of tomato peel fiber and moringa leaf extract. This is understandably due to reduction in red colour with increased addition of tomato peel fiber and moringa leaf extract.

The relationships between the independent variable (tomato peel fiber and moringa leaf extract) and the redness-greenness of the films (dependent variable) are shown in linear equation 14.

$$a^* = +6.62854 - 0.851329 * TPF - 1.78668 * MLE + 0.141717 * TPF * MLE + 0.057443 * TPF^2 + 0.081240 * MLE^2 \quad (14)$$

The overall equation for predicting of effects on tomato peel fiber and moringa leaf extract on the redness-greenness of the films is quadratic. Equation 13 above shows that the linear term for tomato peel fiber showed positive linear effects, while linear term for moringa leaf extract had negative effects. Cross-product terms for tomato peel fiber and moringa leaf extract revealed positive effect, while quadratic terms for both tomato peel fiber and moringa leaf extract showed positive effects.

The analysis of variance (ANOVA) for the model of the redness-greenness (*a**) of TP/TP/MO films was evaluated and found significant ($P \leq 0.05$). The findings from this research are in line with results reported by Singh *et al.*, [21], who reported that chitosan-based edible films incorporated with glycerol as a plasticizer had quadratic effects for redness-greenness (*a**).

Effects of independent variable on the yellowness-blueness (*b) of the edible films**

Table 3 shows the effects of independent factors (tomato peel fiber (TPF) and moringa leaf extract (MLE)) on yellowness-blueness (*b**) of the biodegradable films. According to the results obtained, the yellowness-blueness (*b**) of the edible films was between 2.6667 and 20.6100. While the Run 8 with 1.05 g/100g of TPF and 4.47g/100g of MLE had the lowest score on young modulus, the Run 4 with 10 g/100g of TPF and 2.5 g/100g of MLE posted the highest result for yellowness-blueness (*b**). In another work, yellowness-blueness index (*b**) of edible films made from *acha* starch and *iburu* starch were reported as 1.81±0.007 and 0.53±0.07 respectively [41]. However, research on whey protein edible films incorporated with rapeseed oil revealed decrease in *b** with increase in rapeseed oil. The *b** values of the fabricated edible films ranged from -0.7±0.2 to -0.1±0.2 [42].

The effects of interaction of various levels of incorporation of TPF and MLE on the yellowness-blueness (*b**) of the films is shown in 3D surface response plot shown in Figure 13. From the plot, the incorporation of TPF resulted to increase in yellowness-blueness (*b**) of tomato puree-based films, while increase in MLE lead to a decrease in the yellowness-blueness (*b**). Therefore, while TPF has a positive linear effect, MLE possessed negative linear effects.

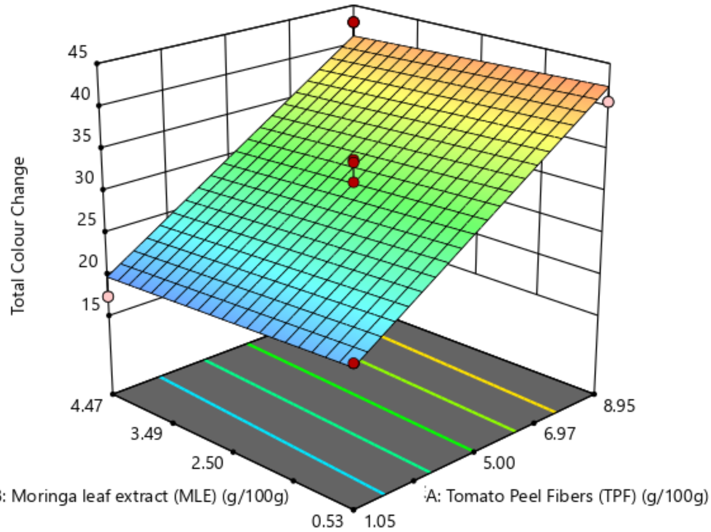

Figure 13. Response plot of effects of TPF and MLE on yellowness-blueness (b) of the edible films

The equation predicting the relationship between TPF and MLE of the edible films is shown in the model below.

$$b^* = +6.22432 + 1.66045 * TPF - 0.498722 * MLE \quad (15)$$

Equation 15 represent the model for the interaction between TPF and MLE to affect the yellowness-blueness (*b**) of the fabricated films. The model equation reveals a linear interaction between tomato peel fibers and moringa leaf extract on the yellowness-blueness (*b**) of the films. The linear interaction of TPF and MLE are positive and negative, respectively.

Analysis of variance (ANOVA) for the model showed that it is significant to describe the relationship between TPF and MLE as regard yellowness-blueness (*b**) of the biodegradable films ($P \leq 0.05$). Contrarily, Singh *et al.*, [21] reported quadratic effects for the effect of levels of incorporation of chitosan and glycerol on edible films for yellowness index.

Effects of independent variable on the Total colour change (ΔE) of the edible films.

Total colour difference of TP/TPF/MLE edible films is presented in Table 3. The total colour difference of the samples ranged between 17.34 to 44.6267. Edible films made from tomato peel fiber (10 g/100g) and moringa leaf extract (2.5 g/100g) had the highest total colour difference. The result of total colour change gotten for the tomato-based edible films compared well with the findings by Galus *et al*. [43], who reported that whey-protein-based edible coatings laced with lemon and lemongrass essential oils had total colour change of within range of observation from this study for whey protein isolate (WPI), whey protein isolate incorporated with lemon essential oils (WPI_LEO) and whey protein isolate incorporated with lemongrass essential oil (WPI_LgEO). A lower colour difference was recorded by Galus and Kadzińska, [42], where incorporation of rapeseed oil into whey protein film increased the total colour difference for films containing 0% to 3% rapeseed oil, respectively. The values for total colour difference reported by Galus and Kadzinka, [42] was lower than values gotten for this research.

The 3D model graphs of the effects of tomato peel fiber and moringa leaf extract on the total colour difference of the biodegradable films is shown in Figure 14. Total colour difference of the TP/TPF/MLE films is positively correlated to the tomato peel fiber amount and negatively correlated (i.e., inverse proportion) with concentration of moringa leaf extract. Thus, increase in tomato peel fiber resulted to an enhanced in total colour difference of the films while decrease in total colour difference was observed for increase in moringa leaf extract.

$$\begin{aligned}&\text{Total colour difference}(\Delta E)\\&=+18.38688+2.69937*TPF-0.324975*MLE \quad (16)\end{aligned}$$

The model equation for the interaction between tomato peel fibers and moringa leaf extract shows linear effects for total colour difference (Equation 16). Both TPF and MLE had linear effects. However, TPF showed a positive effect while on the other hand, MLE had a negative effect.

The variance analysis (ANOVA) for the model conveyed that it is significant to describe the relationship between TPF and MLE as regard total colour difference of the biodegradable films ($P \leq 0.05$). The result from ANOVA implied that the linear model terms of tomato peel fiber and moringa leaf extract significant impact the lightness of the tomato-based edible films. In another study by Chakravartula et al., [44] the total colour difference of the edible film made from various levels of pectin, alginate and whey protein isolate had linear regression effects.

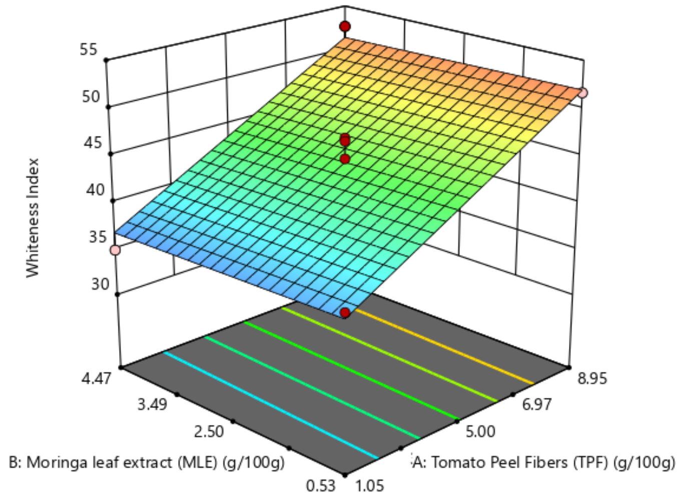

Figure 14. Response plot of effects of TPF and MLE on colour intensity (ΔE) of the edible films

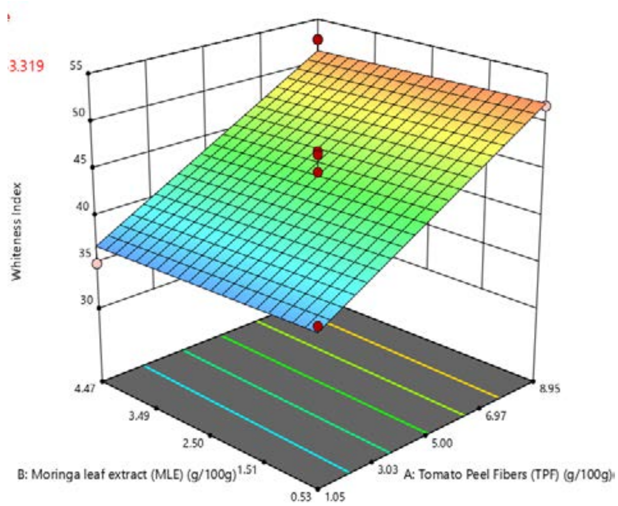

Figure 15. Response plot of effects of TPF and MLE on whiteness index (WI) of the edible films

Effects of independent variable on the whiteness index (WI) of the edible films

The effects of tomato puree, peel fiber and moringa leaf extract on the whiteness index (WI) of the edible films is presented in Table 3. From the results obtained whiteness index ranged between 34.9132 to 53.3190. The sample Run 8 had the lowest value, while Run 4 had the highest lightness parameter. In another research, whiteness index of edible films made from iron yam and maize starch laced with lemon essential oil was reported to be slightly above results for TP/TPF/MLE films [45]. Also, Mohamed *et al*., [46] reported that incorporation of carboxylmethyl-chitosan (CHCH) into casein-based edible films enhanced transparency and invariably whiteness index. In another work by Mohite and Chandel, [47], whiteness index of fenugreek mucilage and taro starch edible films was higher than values gotten for TP/TPF/MLE films. Taro starch improved the whiteness index of the edible films fabricated from fenugreek mucilage and taro starch.

The 3D response plot for whiteness index as affected by levels of tomato peel fiber and moringa leaf extract is shown in Figure 15. From the plot, increase in tomato peel fiber resulted to rise in whiteness index of the edible films. On the other hand, increase in the levels of incorporation of moringa leaf extract cause a decrease in the whiteness index of the films. This is true as moringa leaf extract is black and would diminish the whiteness index of the films, unlike tomato peel fiber with tendency toward whiteness.

The model equation showing the relationship between whiteness index and the levels of incorporation of tomato peel fiber and moringa leaf extract is shown in equation 17.

$$WI = +35.50909 + 1.84606 * TPF - 0.141055 * MLE \quad (17)$$

From the equation, the model equation showing the effects of independent variable on the dependent variables is linear. In terms of the contribution of the model terms, tomato peel fiber had positive effects, while moringa leaf extract showed a negative interaction on the lightness. The test of variance revealed that the terms from the model were significant and adequately fitted at ($P \leq 0.05$). In a study conducted on optimization of physical and optical properties of edible films made from pea starch and guar gum, Saberi *et al*., [30], reported that pea starch and guar gum had quadratic regression effect on the whiteness index (WI) of the fabricated edible films from different incorporation the ingredients.

Effects of independent variable on the water vapour transmission rate (WVTR) of the edible films

Table 4 shows the effects of independent factors - tomato peel fiber (TPF) and moringa leaf extract (MLE)) on water vapour transmission rate (WVTR) of the biodegradable films. From the result obtained, the water vapour transmission rate (wvtr) of the edible films ranged from 1.26 to 14.36 g/m^2/day. While Run 7 with 1.05 g/100g of tomato peel fiber, and 0.53g/100g of moringa leaf extract had the lowest WVTR, the Run 4 comprising 10g/100g TPF and 2.5g/100g had the highest wvtr. In another research, Cai *et al*., [48] reported water vapour transmission rate within range obtained for biopolymer-based functional films made from zein/gelatin and polyethylene in which oregano essential oil was incorporated as active compound. Comparing with Japanese Industrial Standard, the average wvtr (0.00625 – 0.6458 g/m^2/h) of the developed edible films meet the criteria of maximum of 10 g/m^2/h required for acceptable packaging films [49].

The effects of interaction of various levels of incorporation of TPF and MLE on the water vapour transmission rate (wvtr) of the films is shown in 3D surface response plot shown in Figure 16. From the plot, the incorporation of TPF resulted to increase in water vapour transmission rate of tomato puree-based films, while MLE caused a decrease.

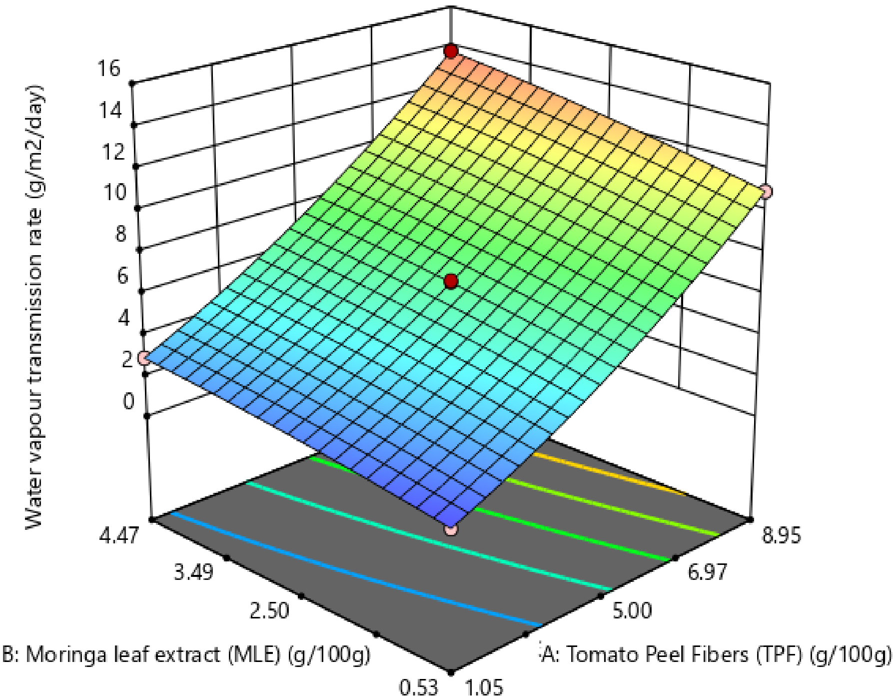

Figure 16. Response plot of effects of TPF and MLE on water vapour transmission rate (WVTR) of the edible films

Equation 18 depicted the relationship between water vapour transmission rate of the TP/TPF/MLE as affected by the levels of incorporation of TPF and MLE. The model equation showed quadratic effects for both TPF and MLE. As regards to each of the model terms, linear effects of both TPF and MLE, cross-interaction between TPF and MLE as well as quadratic term for TPF had positive effects. On the on other hand, the quadratic term for MLE had a negative interaction. This could be because of increase in porosity of the edible films with increased addition of tomato peel fiber.

$$\begin{aligned} WVTR &= +0.151839 + 0.710831 * TPF \\ &+0.597488 * MLE + 0.035001 * TPF * MLE \\ &+0.050045 * TPF^2 - 0.044620 * MLE^2 \end{aligned} \qquad (18)$$

To determine the significant and fitness of the experimental data that define the interaction of the independent factors, with respect to water vapour transmission rate, analysis of variance was conducted. Table 5 showed that the model equation for water vapour transmission rate was significant ($P \leq 0.05$), and the fitness of the model showed insignificant lack of fit. Similarly, Ramesh, *et al*., [50] reported quadratic effects for water permeability for edible films made from avocado seed starch.

Effects of independent variables on the antimicrobial activities of the edible films against *Xanthomonas euvesicatoria*

The effects of tomato peel fiber and moringa leaf extract on the antibacterial activity (against *Xanthomonas euvesicatoria*) of the edible films is shown in Table 4. The bacteria, *Xanthomonas euvesicatoria* was sensitive to the edible films fabricated from TP/TPF/MLE, with diameter of inhibition between 0 to 5.5 mm. The Run 6 (5 g/100g TPF and 5 g/100 g) showed the highest zone of inhibition at 9 mm, while Run 2 (5 g/100g TPF and 0 g/100g) had no inhibitory effects against *Xanthomonas*. In a similar research Alkan and Yemenicioglu, [51] reported that *X. euvesicatoria* was inhibited by zein-based films, impregnated with natural phenolic antimicrobials such phenolic acids, essential oils, and phenolic extract.

The 3D response plot showing the interaction of TPF and MLE as they impact the antibacterial characteristics of the edible films is shown in Figure 17. From the plot, increase in MLE resulted to increased inhibitory activity of the edible films against Xanthomonas, while on the other hand increase in TPF resulted to a decrease in the activities. Thus, increase in moringa leaf extract resulted to an enhanced antimicrobial activity of the films while decrease in activity was observed for increase in tomato peel fiber.

Table 4. Antimicrobial and antioxidant properties of tomato puree, tomato peel fiber and moringa leaf extract edible films

Sample	Tomato peel fiber (g/100g)	Moringa leaf extract	Antimicrobial activity - *Xanthomonas euvesicatoria* (DZI)	Antimicrobial activity - *Alternaria alternata* (DZI)	Antioxidant activity (%)
1	5	2.5	4.0 ± 0.1^{e}	6.9 ± 0.1^{d}	35.3 ± 1.0^{b}
2	5	0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	7.5 ± 1.0^{a}
3	0	2.5	3.0 ± 0.2^{d}	4.9 ± 0.1^{c}	37.2 ± 3.0^{b}
4	10	2.5	2.7 ± 0.1^{cd}	4.4 ± 0.1^{c}	33.9 ± 3^{b}
5	5	2.5	2.5 ± 0.1^{c}	4.7 ± 0.2^{c}	35.4 ± 5.0^{b}
6	5	5	5.5 ± 0.2^{g}	9.0 ± 0.2^{f}	68.8 ± 2.0^{c}
7	1.05	0.53	0.5 ± 0.3^{b}	1.0 ± 0.1^{b}	9.3 ± 3.0^{a}
8	1.05	4.47	5.0 ± 0.1^{f}	8.5 ± 0.5^{ef}	64.1 ± 3.1^{c}
9	5	2.5	3.0 ± 0.1^{d}	4.6 ± 0.5^{c}	36.8 ± 6.0^{b}
10	5	2.5	2.7 ± 0.1^{cd}	4.5 ± 0.5^{c}	34.2 ± 4.0^{b}
11	8.95	0.53	0.6 ± 0.1^{b}	1.0 ± 0.2^{b}	14.0 ± 1.0^{a}
12	8.95	4.47	4.7 ± 0.2^{f}	7.9 ± 0.1^{e}	59.3 ± 3.0^{c}
13	5	2.5	2.8 ± 1.7^{cd}	$4.7\pm\pm0.2^{c}$	30.6 ± 3.0^{b}

Values are the mean of the triplicate analysis + standard deviation (n =3). Values with different superscripts letter along the same column are significantly different ($P \leq 0.05$) using Turkey Test.

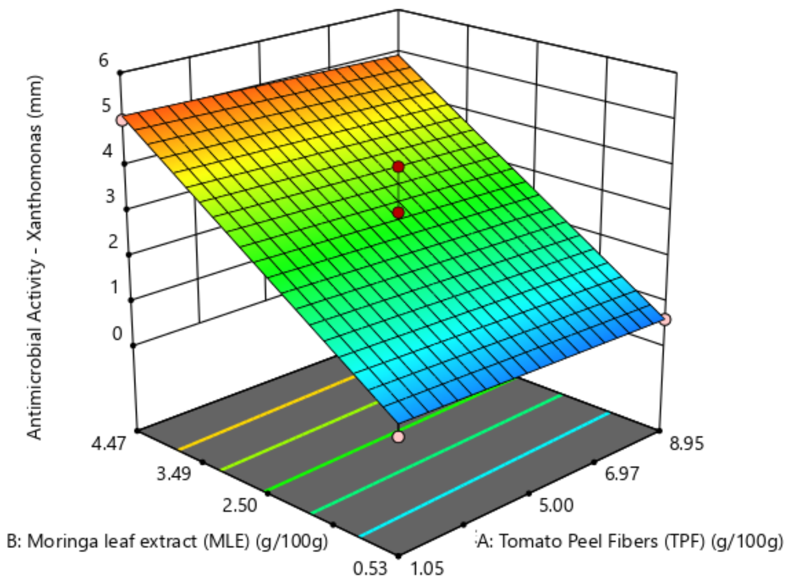

Figure 17. Response plot of effects of TPF and MLE on antimicrobial activity of the edible film

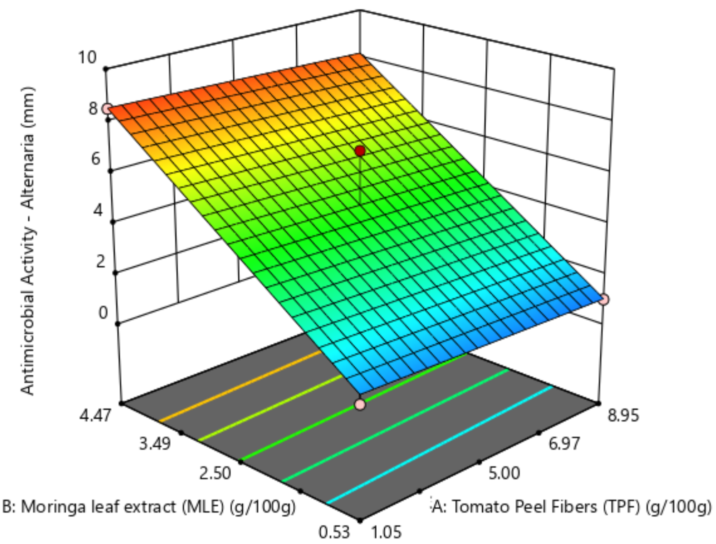

Figure 18. Response plot of effects of TPF and MLE on antimicrobial activity of the edible film against *Alternaria*

The relationships between the independent variable (tomato peel fiber and moringa leaf extract) and the redness-greenness of the films (dependent variable) are shown in linear equation 19.

$$\text{Antibacterial activity } (Xanthomonas) = +0.212363 - 0.020388 * TPF + 1.09429 * MLE \quad (19)$$

The equation for predicting of effects on tomato peel fiber and moringa leaf extract on the antibacterial activity against Xanthomonas of the films showed linear. From the equation, the linear term for tomato peel fiber showed negative linear effects, while linear term for moringa leaf extract had positive effects. The analysis of variance (ANOVA) for the model of the antibacterial activity of TP/TP/MO films was evaluated. The effects of interactions of the tomato peel fiber and moringa leaf extract on overall antibacterial activity of the edible films was significant ($P \leq 0.05$).

Effects of independent variables on the antimicrobial activities of the edible films against *Alternaria alternata*

The effects of tomato peel fiber and moringa leaf extract on the antifungal activity (against *Alternaria alternata*) of the edible films is shown in Table 4. The result obtained for the zone of inhibition of TP/TPF/MLE edible films ranged from 0 to 9 mm. The Run 6 containing 5 g/100g TPF and 5 g/100g had the highest zone of inhibition at 9 mm, while Run 2 made up of 5 g/100g TPF and 0 g/100g had no inhibitory effects against Xanthomonas. Fagundes *et al*., [52] reported effective inhibition of growth of *Alternaria alternata* on cold stored cherry tomatoes coated with hydroxyl methyl cellulose (HPMC) and beeswax (BW) incorporated with glycerol, 2% sodium benzoate and oleic acid.

The 3D surface response plot that showed the effects of independent factors of tomato peel fiber (TPF) and moringa leaf extract (MLE) on the zone of inhibition of the edible films against *A. alternata* is presented in Figure 18. The plot revealed that while increase in the concentration of tomato peel fiber (TPF) caused a reduction in the zones of inhibition of the edible films, the addition of moringa leaf extract caused enhanced of the antifungal activities. Broad spectrum antifungal activities moringa leaf extract and therefore increase zone of inhibition of the edible films with increase moringa leaf extract could attributed to this.

The mathematic equation that explained the effects of tomato peel fiber and moringa leaf extract on the zones of inhibitions against *A. alternata* of the edible films is shown in equation 20.

$$\text{Antifungal activity } (Alternaria) = +0.459523 - 0.043351 * TPF + 1.831366 * MLE \quad (20)$$

From the model equation, while tomato peel fiber showed negative linear effects, moringa leaf extract exhibited positive linear effects. This suggested that increase in moringa leaf extract would result to increase in antifungal properties of the edible film. Contrarily, incorporation of tomato peel fiber caused reduction in the antifungal proprieties of the films. The analysis of variance for the model and terms of interaction between independent factors (tomato peel fiber and moringa leaf extract) and antifungal activities of the edible films showed significant effects.

Effects of independent variables on the antimicrobial activities of the edible films on antioxidant effects of the TP/TPF/MLE films

The antioxidant activities of the fabricated TP/TPF/MLE films are presented in Table 4. From the results obtained the incorporation of moringa leaf extract into the film-forming solutions for TP/TPF/MLE edible films effectively enhance their scavenging activities against the DPPH radicals. The samples of Run 6 with 5 g/100g TPF and 5 g/100g of MLE showed highest free radical scavenging activities against DPPH ($EC_{50} < 0.025$ mg/mL) of 68.8%. Conversely sample Run 2 containing 5 g/100g TP and 0 g/100g of MLE had least DPPH free radical scavenging power of 7.5%. Summarily, increase in proportion of MLE in the film-forming solution of the TP/TPF/MLE edible films resulted to linear increase in DPPH radical scavenging power of the edible films and vice-versa.

The 3D model graphs plot of the effects of tomato peel fiber and moringa leaf extract on the antioxidant effect of the biodegradable films is shown in Figure 19. Antioxidant activity of the TP/TPF/MLE films is positively correlated to the moringa leaf extract levels and negatively correlated (i.e., inverse proportion) with concentration of tomato peel fiber. Thus, increase in moringa leaf extract resulted to an enhanced antioxidant activity of the films while decrease in activity was observed for increase in tomato peel fiber.

The model equation showing the relationship between antioxidant activity and the levels of incorporation of tomato peel fiber and moringa leaf extract is shown in equation 21.

$$\textit{Antioxidant activity} = +5.19893 - 0.178120 * TPF + 12.46128 * MLE \quad (21)$$

The overall equation for predicting of effects on tomato peel fiber and moringa leaf extract on the antioxidant activity of the films is quadratic. Equation 4.14 above shows that the linear term for tomato peel fiber showed negative linear effects, while linear term for moringa leaf extract had positive effects. Cross-product terms for tomato peel fiber and moringa leaf extract revealed negative effect, while quadratic terms for both tomato peel fiber and moringa leaf extract showed negative effects. The analysis of variance (ANOVA) for the model of the antioxidant activity of TP/TP/MO films was evaluated. The effects of interactions of the tomato peel fiber and moringa leaf extract on the DPPH radical scavenging activities of the edible films was significant ($P \leq 0.05$).

Table 5. ANOVA Table for significance of the regression model and fitness statistics for response variables

Regression coefficient	Film thickness	Tensile strength	Elongation at break	Stress at break	Strain at break	Young modulus	Water vapour transmission rate
Constant	0.9528[a]	1.35[a]	1.46[a]	0.5414[a]	4.87a	82.24[c]	6.61[a]
A	0.3958[a]	-2.24[a]	-1.64[a]	-1.53[a]	-5.47a	-38.31[b]	5.13[a]
B	0.0832[b]	-0.2737[c]	0.4137[c]	-0.4079[c]	1.38c	-21.79[c]	1.08[a]
AB	0.1368[b]	0.4273[c]	-0.3687[c]	0.8043[c]	-1.23[c]	-	0.2725[a]
A²	-0.0834[c]	1.12[b]	1.04[a]	1.04c	3.47[a]	-	0.7793[a]
B²	-0.0775[c]	0.4111[c]	-0.3169[c]	0.1896c	-1.06[c]	-	-0.1737[a]
R^2	0.9641	0.9385	0.9035	0.8495	0.9035	0.4315	0.9999
R^2 adj	0.9384	0.8946	0.8346	0.7419	0.8345	0.3178	0.9998
Model *F*-value	37.57	21.36	13.11	7.9	13.11	3.8	10079.43
Lack of fit (p value)	0.0897	0.4468	0.0043	0.3069	0.0043	0.0374	0.9756

[a]significant at 0.01 level; [b]significant and 0.05 level; [c]significant at 0.1 level

Table 5. contd: ANOVA Table for significance of the regression model and fitness statistics for response variables

Regression coefficient	*L**	*a**	*b**	Total Colour Change	Whiteness Index	Antimicrobial Activity - Xanthomonas	Antimicrobial Activity - Alternaria	Antioxidant Activity
Constant	46.49[a]	1.62[a]	13.28[a]	18.38688[a]	44.39[a]	0.212363[a]	0.459523[a]	35.46[a]
A	9.1[a]	0.3054[c]	6.55[a]	2.69937[a]	7.28[a]	-0.020388[c]	-0.043351[c]	-0.7029[c]
B	-0.4437[c]	-1.33[a]	-0.984[c]	-0.324975[c]	-0.2783[c]	1.09429[a]	1.81366[a]	24.59[a]
AB		1.1[a]	-	-	-	-	-	-
A²		0.8944[c]	-	-	-	-	-	-
B²		0.3162[c]	-	-	-	-	-	-
R^2	0.8642	0.8444	0.8863	0.8978	0.8315	0.9532	0.9484	0.9827
R^2 adj	0.8371	0.7333	0.8635	0.8774	0.7978	0.9439	0.9381	0.9793
Model *F*-value	31.82	7.6	38.96	43.92	24.67	101.92	91.88	284.36
Lack of fit (p value)	0.9209	0.0278	0.2926	0.8814	0.9532	0.9844	0.9822	0.3251

[a]significant at 0.01 level; [b]significant and 0.05 level; [c]significant at 0.1 level

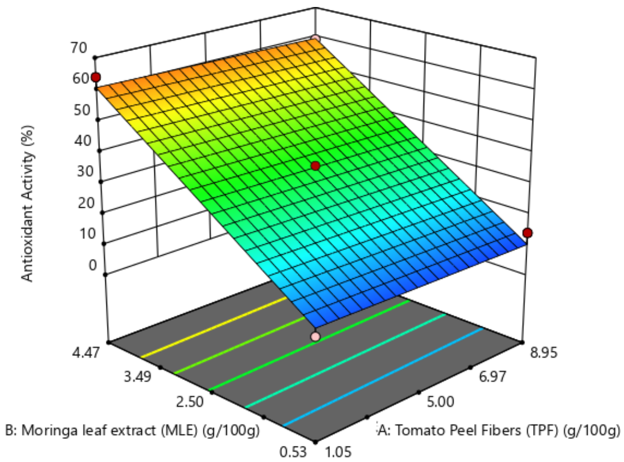

Figure 19. Response plot of effects of TPTPFMLE on antioxidant activity of the edible film

Optimization and validation of the edible films' formulations

To obtain the best performing edible film the optimization of different levels of TP/TPF/MLE was done for thickness, mechanical properties (tensile strength, elongation at break, stress at break, strain at break and young modulus), color (*L**, *a**, *b**, total colour, whiteness index), water vapor transmission, antimicrobial activity, and antioxidant activity. This was achieved by superimposition of areas of desirability for the selected parameters. The degree of desirability for each of the parameters ranged from 1 to 10, where 1 represented the least desired and ten (10) stood for the best combo to give the most desirable effects. Specifically, in consideration of the above approach, the objective was to maximize tensile strength, elongation at break, young modulus, whiteness index, antimicrobial activity, and antioxidant properties, while water vapour transmission rate was minimized. Other parameters, thickness, stress at break, strain at break, *L**, *a**, *b**, and total colour change were held in range.

The superimposition of the film parameters based on desirability to maximize, and minimize effects resulted to optimum formulations of the film-forming solution of the TP/TPF/MLE edible films. The optimum edible film formulation was determined based on the combinations from tomato peel fibers (0 - 10 g/100 g of tomato puree), and moringa leaf extract (0 - 5 g/100 g of tomato puree). From the result of the superimposed plots, the optimal formulation (independent variables) that gave the best performing edible films were 2.684 g of tomato peel fiber and 0.527 g of moringa leaf extract in 100 g tomato puree based. The obtained desirability for this combination was 0.667. The desirability plot and overlay plot are depicted in Figure 20.

To verify the accuracy of prediction of the results generated from superimposition of the desirable points of the dependent variables, the optimal formulation was applied to the production of edible films and the dependent variables evaluated. The actual results obtained was compared with the predicted values from the mathematical modelling. The predicted and actual values of the dependent variables the optimized TP/TPF/MLE edible films were significantly similar at statistical confidence level of 95%. The data showing the comparison between the predicted and actual responses of the TP/TPF/MLE edible films is presented in Table 6 and Figure 21.

Table 6. Predicted and experimental values for the mechanical antimicrobial and antioxidant properties of the TP/TPF/MLE films

Responses	Predicted values[a]	Experimental value[b]
Film thickness (mm)	0.89	0.81
Tensile strength (N/mm^2)	1.74	1.69
Elongation at break (mm)	1.83	1.9
Stress at break (N/mm^2)	0.44	0.5
Strain at break (%)	6.12	6.43
Young modulus (N/mm^2)	65.42	66.2
Water vapour transmission rate (WVTR) g/m^2/d	6.83	6.8
*L** (Lightness)	44.86	43.3
*a** (Redness)	0.44	0.5
*b** (Blueness)	11.45	10.05
Total colour change (ΔE)	29.05	30.1
Whiteness Index (WI)	43.16	41.36
Antimicrobial activity -Xanthomonas	5.02	5.46
Antimicrobial activity – Alternaria	8.38	1.2
Antioxidant activity	60.14	55.72

[a]Predicted value from the model equation. [b]Observed values obtained for optimised film. cAbsolute residual error. R^2 correlation between predicted and oberved values (0.997).

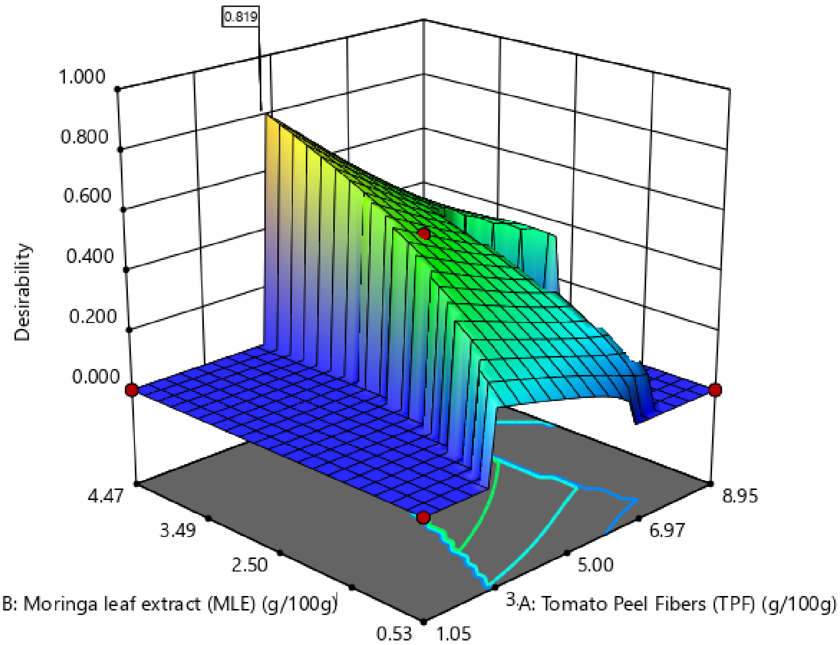

Figure 20. 3D desirability plot of optimized TPTPFMLE films

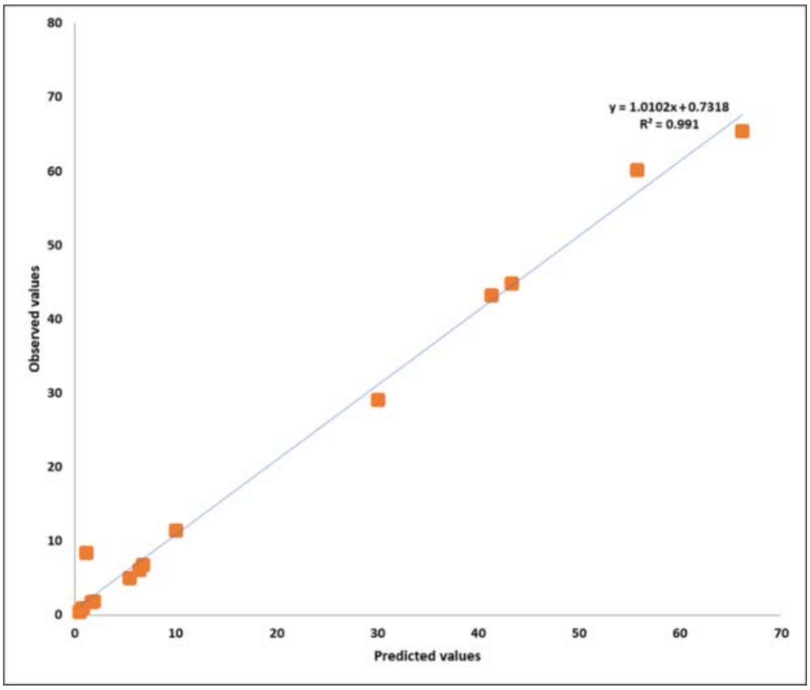

Figure 21. Parity plot showing the distribution of experimental versus predicted values by the mathematical model of the y values

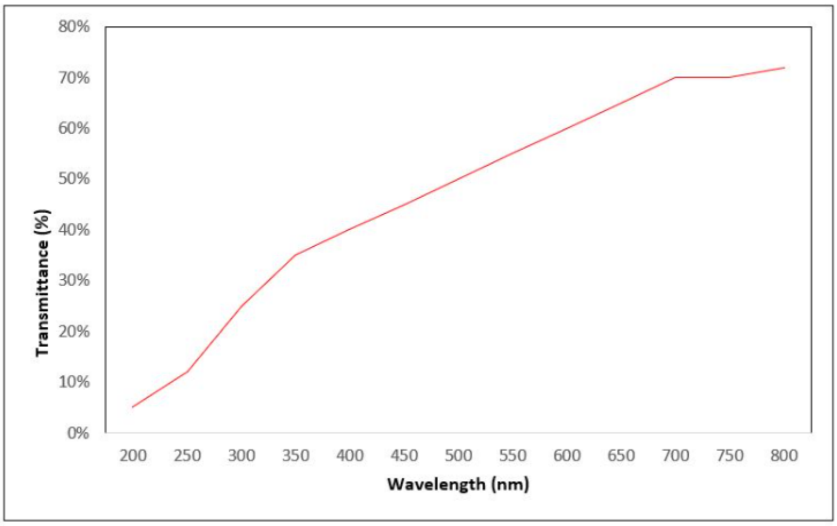

Figure 22. UV absorption spectra of optimized films

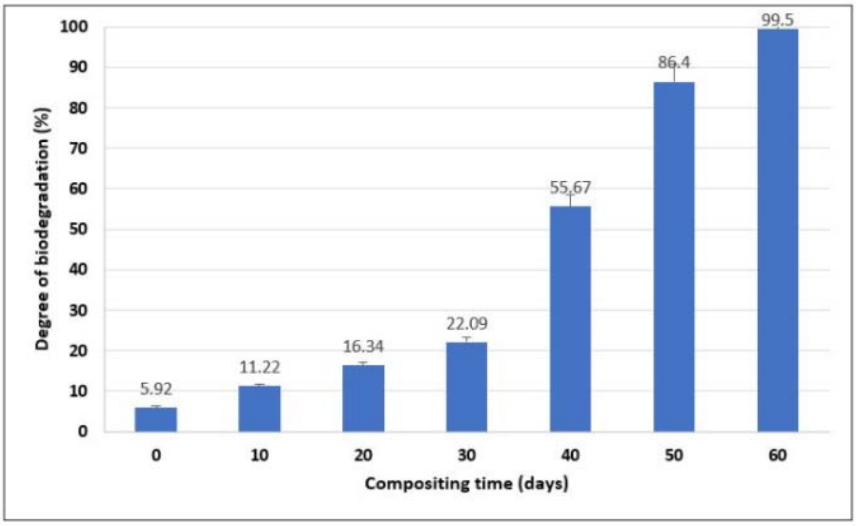

Figure 23. Changes in degradation of optimized film

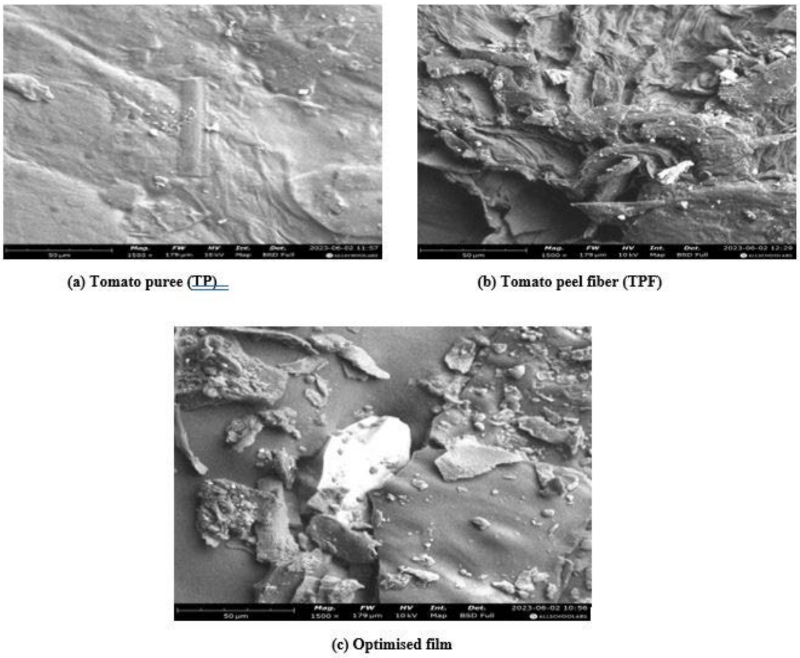

Figure 24. Scanning electron micrograph of (a) tomato puree, (b) tomato peel fiber, and (c) optimized edible films at 1500x magnification

Light transmittance of the optimized film

The light transmission spectra of the optimized edible film are shown in Figure 22. From the spectra, the maximum (5%) and minimum (72%) absorption was at 200 and 800 nm, respectively. The results obtained indicated that the edible film possess potential ability to function as a UV barrier against loss of nutrients, lipid oxidation, loss of colour and flavour of foods. The inclusion of moringa leaf extract reduced light transmission and increased light dispersion. Due to this, light transmission in the UV area decreased, while resistance to UV light increased. The results reported by Zhang *et al*., [53], in which gum ghatti was reported to display similar resistance against light. The observation reported for this research was ascribed to the dispersion ability of sorbitol and glycerol on the films that resulted to a breakdown in the structural arrangement of the film. One of the typical food breakdown catalysts that leads to lipid oxidation is UV radiation. As a result, it is one of the crucial indications while researching appropriate food packing materials.

Film biodegradability of the optimized film

The trend in the degree of biodegradation of the optimized edible film over a period of 60 days burial is represented in Figure 22. The degree of biodegradation of the film revealed 86.5, 55.67, 22.09, 16.34, 11.22 and 5.92% for 60 days (10 days interval) compositing period. The biodegradability rate of the optimized film increased form 0.669%/day in the first 30 days of burial to 1.65%/day after 60 days. The results obtained showed a good degree of biodegradability for the optimized edible films and satisfied the property of eco-friendliness and sustainability. This is similar with the findings of Tarique *et al*., [26], which reported biodegrability rate of 1.48 to 3.87% for arrowroot starch biopolymers, plasticized with glycerol at 15, 30 and 45%. Incorporation of glycerol caused decrease in biodegradability rate of the arrowroot starch films, with the formulation made with 45% glycerol showing a rate of 1.46%/day.

Morphological characteristics of the optimized film

Characterization of the morphology of the optimized edible films was studied using scanning electron microscopy (SEM). SEM examination assists in examining the homogeneity, smoothness, and existence of fractures on the films' surface, which can affect the mechanical characteristics of films and applicability. Figure 24 showed the scanning electron microscope images of the tomato puree, tomato peel fiber, and the optimized film cross-section with 1500 X magnification. The scanning electron micrographs of the film showed that tomato peel fiber exhibited highest roughness level, followed by tomato puree. The optimized film, had partial rough and smooth regions and this could be because of low interfacial adhesion between tomato puree, tomato peel fiber and moringa leaf extract. The findings for tomato peel fiber are in line with morphological result reported by Bugatti *et al*., [54] on microstructure of untreated tomato peel fiber. From their finding, tomato peel fiber exhibited porous structure with great deal of roughness. Incorporation of pectin as a plasticizer effectively improved roughness of the edible film. Also, this behavior can be explained because of heterogeneity of the film composition, tomato puree, tomato peel fiber, and moringa leaf extract. A similar pattern was reported by Tarique *et al*., [26] who reported that a film developed from arrowroot starch biopolymers, in which the film sample comprised of 45% glycerol had greater homogeneity, comparable to films with 15% and 30% glycerol. Freitas *et al*., [55] reported increased surface roughness of films produced from bacteria cellulose/tomato puree, CMC, and palm olein because of heterogeneity of the composition. The roughness of both the surface and cross-section of the bacteria cellulose/tomato puree-based edible films were ascribed to due to heterogeneity of the composite materials [53]. Similarly, Oliveira *et al*., [56] reported that incorporation of kale puree in an alginate-based edible films increased the surface roughness of the morphology. The research noted that agglomerated were introduced with addition of kale puree and the phenomenon was attributed to interaction between the polymer and kale fibers. Shanbhag *et al*., [57] reported that microstructure of edible films made from different combinations of arrowroot powder, cornstarch, refined wheat flour, glycerol, pectin, and vinegar showed a smooth surface, with little micropores.

4. Conclusions

The study showed that suitable bioactive and biodegradable edible films can be produced from tomato puree, tomato peel fiber and moringa leaf extract. Central composite orthogonal design (CCOD) was effective in design and determination of the effects of tomato peel fiber and moringa leaf extract on the physical, mechanical, optical, antimicrobial and antioxidant properties of the developed edible films. Addition of tomato peel fiber improved mechanical properties of the films. There was positive correlation between increase in tomato peel fiber and tensile strength. The tensile strength of the edible films was above 0.39 MPa standards for industrial packaging films. Moringa leaf extract enhanced the antimicrobial and antioxidant properties of the developed edible film. The incorporation of moringa leaf extract deterred microbial attack Xanthomonas and Alternaria. The zones of inhibition of the microorganisms increased with rise in moringa leaf extract.

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