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DEVELOPMENT AND CHARACTERIZATION STUDY OF EDIBLE FILM FOR FOOD APPLICATIONS FROM *MUSA ACUMINATA* "RED DACCA"

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Abstract
Fruit processing industry is labeled as high residue producing industry. There are several by-products including peel, seed, stalk and roots which may contain a large number of bioactive components. Banana is a low profile food for developing countries. The peel of banana is discarded as waste which is about 1/3rd of fruit weight. There are more than 50 varieties of banana were cultivated in India and 20 varieties were commonly grown across India. The banana peel, an underutilized by-product, was used to prepare flour and phytochemical analysis was performed. The flour is expected to be responsive to high antioxidant activity and nutritional value. We have developed an edible packaging film from the flour of the Banana Peel, which can be used for numerous food applications. The film was prepared with different ratio of flour and glycerol and it was characterized in terms of thermal, mechanical, microbiological and moisture barriers., film forming ability and sensory properties. The most proper film formulation was chosen based on the response of Preliminary formulation. In further process the selected film was evaluated on basis of water resistances, color & light barrier, tensile properties, FT-IR Spectra for edible film and anti-microbial activity. The banana peel floor is a promising material to develop edible film.

INTRODUCTION

In recent years, there has been tremendous innovation in the production of biopolymer-based films, particularly for applications in the food industry. Biopolymer-based films are bio-based materials prepared from naturally occurring biopolymers such as polysaccharides, proteins, and lipids [Falguera *et al.,* 2011; Rhim *et al.,* 2013]. There has been considerable interest in developing and utilizing biodegradable packaging materials characterized by unique biological, mechanical, and thermal properties for modern food packaging applications [Falguera *et al.,* 2011; Rhim *et al.,* 2013; Siracusa *et al.,* 2008].

Biodegradable packaging plays a vital role in food preservation, shelf-life extension, and the reduction of environmental problems associated with conventional synthetic plastics [Rhim *et al.,* 2013; Siracusa *et al.,* 2008]. Active biopolymer-based films reinforced with nanomaterials such as mineral clays, nanocellulose, and natural fibres have been considered promising alternatives to petroleum-based synthetic plastics in food packaging [Siracusa *et al.,* 2008; Azeredo *et al.,* 2009]. The incorporation of these reinforcing materials can improve the mechanical strength, thermal stability, and barrier properties of biodegradable films [Siracusa *et al.,* 2008; Azeredo *et al.,* 2009].

Edible films are materials that can be consumed directly along with food products. They act as protective barriers and can improve the quality and safety of food by reducing moisture transfer, gas exchange, oxidation, and microbial deterioration [Pavlath *et al.,* 2009; Hassan *et al.,* 2018]. One of the most significant advantages of edible packaging systems over synthetic packaging systems is that they can become an intrinsic component of the food product and may be consumed without the need to unpack and discard the packaging material [Pavlath *et al.,* 2009].

Furthermore, edible films are typically prepared from renewable and edible materials, providing the important advantages of biodegradability and environmental sustainability [Falguera *et al.,* 2011, Pavlath *et al.,* 2009].They are not necessarily intended to completely replace traditional packaging materials; instead, they can be used in combination with non-edible packaging systems to provide additional protection and extend the shelf life of food products [Pavlath *et al.,* 2009; Hassan *et al.,* 2018]. Edible and biodegradable films can be prepared from a wide range of natural materials, including polysaccharides, proteins, lipids, starch, cellulose, pectin, and agricultural by-products [Falguera *et al.*, 2011; Rhim *et al.,* 2013].

Among the various agricultural wastes, banana peel has emerged as a promising raw material for the production of biodegradable and edible films [Mohapatra *et al.,* 2010; Happi Emaga *et al.,* 2007]. Banana peel contains valuable components, including dietary fibre, cellulose, pectin, starch, phenolic compounds, carotenoids, and other antioxidant substances [Mohapatra *et al.,* 2010; Happi Emaga *et al.,* 2007; Someya *et al.,* 2002]. These compounds can contribute to the functional properties of biodegradable films and may provide antioxidant activity and improved physicochemical characteristics [Happi Emaga *et al.,* 2007; Someya *et al.,* 2002].

Banana peels are generally discarded as agricultural and household waste despite their considerable potential for value-added applications. Large quantities of banana residues are generated during domestic consumption and food processing, creating environmental concerns related to waste disposal [Mohapatra *et al.,* 2010; Padam *et al.,* 2014]. Banana waste can be utilized for applications such as composting, fertilizer production, wastewater treatment, animal feed, and the extraction of valuable bioactive compounds [Mohapatra *et al.,* 2010; Padam *et al.,* 2014]. However, the conversion of banana peel into biodegradable and edible packaging films represents an innovative and sustainable approach to agricultural waste valorization.

The utilization of banana peel for edible film production can therefore contribute to both environmental sustainability and the development of eco-friendly food packaging materials. Banana peel-derived components such as starch, pectin, cellulose, and dietary fibre possess film-forming potential and can be utilized to develop biodegradable materials [Happi Emaga *et al.,* 2007; Someya *et al.,* 2002; Padam *et al.,* 2014]. Thus, the development of banana peel-based edible films may help reduce dependence on synthetic plastics while simultaneously minimizing the accumulation of organic waste.

Among the different varieties of banana, red banana is of particular interest because of its distinctive colour, nutritional composition, and bioactive compounds. Red bananas are commonly associated with Musa acuminata and cultivars belonging to the AAA genome group, including varieties commonly referred to as Red Dacca [Simmonds, 1987, Englberger *et al.,* 2006]. They are characterized by their reddish to reddish-purple or maroon-coloured peel, which distinguishes them from the commonly consumed yellow Cavendish bananas [Simmonds, 1987].

Red bananas may vary in size and shape depending on the cultivar. Some varieties are relatively small and plump, whereas others are larger [Simmonds, 1987, Englberger *et al.,* 2006]. The fruits contain important nutrients, including carbohydrates, dietary fibre, potassium, and other minerals, as well as bioactive compounds such as carotenoids and phenolic substances [Englberger *et al.,* 2006; Davey *et al.,* 2009; Pereira *et al.,* 2015]. The characteristic red colour of the fruit is associated with the presence of carotenoids and other pigments, which may contribute to its antioxidant properties [Englberger *et al.,* 2006; Davey *et al.,* 2009].

Studies have demonstrated that different banana cultivars exhibit variations in their nutritional composition and concentrations ofcarotenoids, vitamin C, phenolic compounds, and minerals [Englberger *et al.,* 2006; Davey *et al.,* 2009]. Therefore, the nutritional properties of red bananas should be considered cultivar dependent. Their reddish pigmentation and bioactive composition make red banana and its peel particularly interesting for the development of functional and sustainable biomaterials.

Like other bananas, red bananas ripen rapidly under ambient conditions, and their post-harvest quality is influenced by temperature and storage conditions [Davey *et al.,* 2009; Dadzie *et al.,* 1997]. Appropriate post-harvest handling and storage are important for maintaining fruit quality and reducing deterioration. The peel generated after consumption represents a valuable source of biopolymers and bioactive compounds that can potentially be converted into value-added products.

Therefore, the utilization of red banana (Musa acuminata, AAA group) peel for the development of biodegradable and edible films represents a promising approach toward sustainable food packaging. The conversion of red banana peel, an agricultural waste material, into a functional packaging film may contribute to waste reduction, environmental protection, and the replacement or reduction of conventional petroleum-based plastics. Furthermore, the presence of natural biopolymers and antioxidant compounds in banana peel provides potential for developing functional edible films with applications in food preservation and shelf-life extension.

MATERIALS AND METHODS

3.1 Collection of Banana Waste

Fully grown, mature bananas of similar size were purchased from a local market. The fruits were carefully inspected, and bananas showing bruises, mechanical injuries, microbial spoilage, or other visible defects were excluded. Healthy and undamaged bananas were selected to ensure uniformity and consistency in the preparation of banana peel flour and edible films. The collected banana peels were subsequently processed for the preparation of flour as described below [Falguera *et al.,* 2011; Rhim *et al.,* 2013].

3.2 Production of Banana Peel Flour

Banana peel flour (BPF) was prepared with slight modifications to previously reported methods for the utilization of banana by-products in food and biomaterial applications [Falguera *et al.,* 2011; Rhim *et al.,* 2013; Siracusa *et al.,* 2008].

Step 1: Cleaning and Preparation

The peels were manually separated from the bananas using a clean stainless-steel knife. The collected peels were thoroughly washed with distilled water to remove adhering dirt, dust, and other impurities.

Step 2: Prevention of Enzymatic Browning

The cleaned banana peels were soaked in brine solution for 15 min and subsequently rinsed with distilled water. This treatment was performed particularly for ripe banana peels to minimize enzymatic browning and undesirable colour changes during processing. Pretreatment of fruits and vegetables before drying has been widely employed to reduce browning and improve the quality of the final dried product [Siracusa *et al.,* 2008; Azeredo *et al.,* 2009].

Step 3: Drying

The treated banana peels were dried in a tray dryer at 120°C for 3 h, or until a constant moisture content was obtained. Drying was carried out to reduce the moisture content and improve the storage stability of the resulting flour [Padam *et al.,* 2014; Sagar *et al.,* 2010].

Step 4: Milling and Sieving

The dried banana peels were milled using a suitable grinder to obtain a fine powder. The powder was subsequently sieved using a laboratory sifter to obtain uniform particle size and fine banana peel flour.

Step 5: Storage

The prepared banana peel flour was hermetically sealed in suitable containers and stored at ambient temperature until further analysis and film preparation.

3.3 Development of Edible Film

Edible films were prepared by the solvent-casting method, which is commonly used for the preparation of biopolymer-based and edible films [Falguera *et al.,* 2011; Pavlath *et al.,* 2009; Hassan *et al.,* 2018].

Step 1: Preparation of Film-Forming Solution

Banana peel flour (BPF) and wheat peel flour (WPF) were dispersed in 100 mL of distilled water and mixed thoroughly until a uniform dispersion was obtained. Glycerol was added as a plasticizer to improve the flexibility and handling properties of the edible films [Pavlath *et al.,* 2009; Hassan *et al.,* 2018].

Step 2: Formulation of Different Film Samples

Different concentrations and combinations of BPF, WPF, and glycerol were prepared according to the formulations presented in Table 3.1.

Step 3: Heating

The film-forming mixture was heated at 90–95°C for 5 min with continuous stirring. The heated mixture was subsequently allowed to cool to approximately 50°C.

Step 4: Casting and Drying

The resulting viscous film-forming solution was cast onto sterile Petri dishes with a diameter of 9 cm. The cast films were dried in a tray dryer at 120°C for 4 h until dry films were obtained.

Step 5: Conditioning

The dried films were carefully removed from the Petri dishes and conditioned at 22–23°C for 72 h at approximately 58% relative humidity (RH) before further characterization. Conditioning of films under controlled temperature and relative humidity is important for obtaining reproducible physical and mechanical properties [Pavlath *et al.,* 2009; Hassan *et al.,* 2018].

Step 6: Selection of Film

The prepared films were visually evaluated for film-forming ability, ease of peeling, handling characteristics, and transparency. The formulation exhibiting the most desirable functional characteristics was selected for further analysis.

Table 3.1. Response of Preliminary Film Formulations

BPF (%)	WPF (%)	Glycerol (%)	FFA	Peeling off	Handling	Transparency
1.5	0.5	1.0	−	−	−	++
2.5	0.5	1.0	−	−	−	++
2.0	2.0	1.0	+	+	++	−
3.0	1.5	1.0	++	++	++	+
3.0	1.5	1.5	++	++	+	+

Note: BPF – Banana Peel Flour; WPF – Wheat Peel Flour; G – Glycerol; FFA – Film-Forming Ability.
++: Excellent; +: Acceptable/Good; −: Poor or absent.

3.5 Characterization and Properties of the Film

3.5.1 Water Resistance

Water resistance was evaluated for the selected edible film. The film samples were fixed over the opening of test cells having an exposed surface area of 16 cm^2. Distilled water (2.5 mL) was carefully poured onto the surface of the film. The deformation of the film and the volume of water passing through the film were recorded over time. The observations were continued until film failure or for a maximum period of 25 h. Water resistance is an important property for evaluating the suitability of biodegradable films for food packaging applications [Pavlath *et al.,* 2009; Happi Emaga *et al.,* 2007].

3.5.2 Water Vapour Permeability

Water vapour permeability (WVP) was determined using a gravimetric method based on ASTM E96/E96M with suitable modifications [Someya *et al.,* 2002]. A test film was sealed over an acrylic cup containing anhydrous calcium chloride ($CaCl_2$) as a desiccant. The complete assembly was weighed and placed inside a chamber containing distilled water to maintain a high relative humidity.

The relative humidity inside the chamber was maintained at approximately 99%, and the temperature was maintained at 20°C. A fan was operated continuously during the experiment to ensure uniform relative humidity within the chamber. The weight gain of the cups was measured periodically at hourly intervals for 6 h.

The water vapour transmission rate (WVTR) was obtained from the slope of the linear regression between weight gain and time, with regression coefficients maintained at $R^2 > 0.99$.

The thickness of each film was measured at four different locations, and the mean thickness was used for calculating WVP.

The water vapour permeability was calculated using the following equation:

$$WVP = (WVTR \times e) / \Delta P$$

Where:
WVP = Water vapour permeability (g m^{-1} s^{-1} Pa^{-1})
WVTR = Water vapour transmission rate (g m^{-2} s^{-1})
e = Mean film thickness (m)
ΔP = Difference in water vapour partial pressure across the film (Pa)

The WVTR was determined from the slope obtained by plotting the weight gain of the sample against time [ASTM International, 2024, McHugh *et al.,* 1994].

3.5.3 Oxygen Transmission Rate

The oxygen transmission rate (OTR) is defined as the steady-state rate at which oxygen gas permeates through a packaging film under specified temperature and relative humidity conditions. OTR is generally expressed as the volume of oxygen transmitted through a specified area of film during a defined period, commonly expressed as cm^3 m^{-2} day^{-1} [Simmonds, 1987; ASTM International, 2024].

Oxygen barrier properties are important in food packaging because oxygen transmission can influence lipid oxidation, colour deterioration, nutrient degradation, and microbial growth in food products [Pavlath, 2009; ASTM International, 2024]. The oxygen transmission properties of the selected edible film were evaluated according to an appropriate standard method for oxygen gas transmission through plastic films and sheets.

3.5.4 Fourier Transform Infrared Spectroscopy (FTIR)

The functional groups and molecular interactions present in the edible films were analysed using an attenuated total reflectance—Fourier transform infrared (ATR–FTIR) spectrometer. The infrared spectra were recorded over the wavenumber range of 4000–600 cm^{-1}, with a resolution of 4 cm^{-1}. A total of 32 scans were averaged for each spectrum.

Before FTIR analysis, the films were stored in a desiccator containing silica gel for one week to reduce moisture interference. The thin film samples were then placed directly onto the ATR crystal for spectral analysis. FTIR analysis is widely used to identify functional groups and investigate intermolecular interactions in biopolymer-based films [Hassan *et al.,* 2018; Kačuráková *et al.,* 2001].

3.5.5 Film Solubility

The water solubility of the edible films was determined using a gravimetric method [Hassan *et al.,* 2018, Davey *et al.,* 2009]. Film samples measuring 2 cm × 3 cm were cut and stored in a desiccator containing silica gel for 7 days. The conditioned samples were weighed to determine their initial dry weight.

Each film sample was placed in a beaker containing 80 mL of deionized water and maintained under constant agitation at 200 rpm for 1 h at 25°C. The undissolved film residues were collected by filtration and dried in an oven at 60°C for 24 h, or until a constant weight was obtained.

The percentage solubility was calculated using the following equation:

$$\% \text{ Solubility} = [(\text{Initial dry weight} - \text{Final dry weight}) / \text{Initial dry weight}] \times 100$$

Film solubility is an important characteristic that determines the potential application of edible films under different food storage conditions [Hassan *et al.,* 2018; Gontard *et al.,* 1993].

3.5.6 Microbiological Quality of the Edible Film

For microbiological evaluation, the film formulation exhibiting the best functional characteristics was selected. The microbiological quality of the selected edible film was evaluated by determining the viable counts of total aerobic mesophilic bacteria, Enterobacteriaceae, and Staphylococcus aureus.

The microbial load of the film was evaluated after 1 day and 1 year of storage under ambient temperature and approximately 58% RH. All analyses were performed in duplicate.

An initial dilution was prepared by aseptically transferring 1 g of film into 9 mL of 0.1% buffered peptone water. Serial decimal dilutions were subsequently prepared under aseptic conditions.

The viable total aerobic mesophilic bacterial count was determined using the pour plate method with Plate Count Agar. The inoculated plates were incubated at 30°C for 72 h, and the microbial counts were expressed as colony-forming units per gram (CFU/g) [ISO, 2013; Salfinger, *et al.,* 2015].

Appropriate selective culture media and incubation conditions were used for the enumeration of Enterobacteriaceae and Staphylococcus aureus according to standard microbiological procedures [ISO, 2013; Salfinger *et al.,* 2015; Bauer *et al.,* 1966].

3.5.7 Antimicrobial Activity

The antimicrobial activity of the edible film exhibiting the best functional characteristics was evaluated using the agar diffusion method. Selected test microorganisms were cultured under appropriate laboratory conditions, and the microbial suspension was uniformly inoculated onto the surface of agar plates.

Film samples of uniform size were placed on the inoculated agar surface and incubated under suitable conditions depending on the test microorganism. The antimicrobial activity was determined by measuring the clear zone of inhibition surrounding the film samples.

The diameter of the growth inhibition zone was measured in millimetres (mm). A larger inhibition zone indicated greater antimicrobial activity of the film against the tested microorganism [Balouiri *et al.,* 2016; Stone *et al.,* 2012].

3.5.8 Sensory Analysis

Sensory evaluation is a scientific discipline used to evoke, measure, analyse, and interpret human responses to the characteristics of food and related materials as perceived through the senses of sight, smell, taste, touch, and hearing [ASTM International, 2024].

The sensory characteristics of the developed edible film were evaluated using appropriate sensory parameters. Depending on the intended application, the evaluated attributes included appearance, colour, transparency, texture, odour, taste, mouthfeel, and overall acceptability.

The sensory evaluation was conducted using a suitable panel of evaluators under controlled conditions. The samples were coded and presented randomly to minimize bias. The sensory scores were recorded using an appropriate hedonic or descriptive scale [ASTM International, 2024; ; Kačuráková *et al.,* 2001].

RESULTS AND DISCUSSION

Preliminary experiments were conducted to identify the most suitable formulation for preparing edible films by the casting method (Table 3.1). Film formation was influenced by the concentration and proportion of banana peel flour (BPF), whole banana flour (WBF), and glycerol. The formulation containing 1.5% BPF, 0.5% WBF, and 1% glycerol did not produce a continuous film. Similarly, formulations with insufficient concentrations of film-forming materials showed poor film-forming ability.

In contrast, the formulation containing 3% BPF and 1.5% WBF with 1% glycerol produced a continuous film with satisfactory peeling and handling characteristics. Therefore, this formulation was selected for further characterization.

The ability of biopolymer-based materials to form continuous films depends on the concentration and interactions of polysaccharides, proteins, fibres, and other film-forming components. Adequate concentrations of these components are necessary to form a continuous polymeric matrix during solvent evaporation [Falguera *et al.,* 2011; Rhim *et al.,* 2013]. Glycerol acts as a plasticizer by increasing molecular mobility and flexibility; however, its concentration must be optimized because excessive plasticizer may weaken the intermolecular interactions responsible for film formation [Gontard *et al.,* 1993, Siracusa , 2012].

Water resistance represents the ability of a film to withstand contact with water without losing its structural integrity. In the present study, the developed films showed good resistance to water. After exposure to water, only a small deformation of ≤0.5 cm was observed due to the weight of water on the film surface. After approximately 25 h, water dripping through the film was detected; however, the amount of water filtered did not exceed 1.75 mL.

Importantly, water penetration did not result in visible breakage or pore formation, indicating the formation of a relatively stable film matrix. The stability of edible films in the presence of water depends on the interactions among the film-forming biopolymers and the hydrophilic or hydrophobic nature of their components [Pavlath *et al.,* 2009; Hassan *et al.,* 2018].

Banana peel flour contains polysaccharides, dietary fibre, cellulose, pectin, and other structural components that may contribute to the formation of a reinforced polymeric network [Mohapatra *et al.,* 2010; Happi Emaga *et al.,* 2007]. Strong intermolecular interactions among these components can improve the structural integrity and resistance of the film. The presence of glycerol did not adversely affect the water resistance of the selected formulation, suggesting that the amount of plasticizer used was appropriate for maintaining flexibility without excessive disruption of the film matrix. Similar effects of plasticizer concentration on the water resistance and structural properties of edible films have been reported previously [Gontard *et al.,* 1993, Siracusa , 2012].

Water vapour permeability (WVP) is an important characteristic of edible films because it determines the ability of a packaging material to control moisture transfer between food and the surrounding environment. The WVP values obtained for the developed banana peel and whole banana flour film were comparatively low when compared with values reported for edible films prepared from other flour-based materials.

Previous studies have reported WVP values of 45.79 ± 0.2 g mm m^{-2} d^{-1} kPa^{-1} for achira flour films, 6.05 ± 0.2 g mm m^{-2} d^{-1} kPa^{-1} for amaranth flour films, and 18.14 ± 0.2 g mm m^{-2} d^{-1} kPa^{-1} for banana flour films prepared under different formulation conditions.

The comparatively low WVP observed in the present study may be related to the composition and structure of the developed film. The relatively low concentration of glycerol may have reduced excessive molecular mobility and limited the formation of pathways for water vapour diffusion. In addition, the high dietary fibre content of banana peel flour may have contributed to the formation of a compact and tortuous matrix, thereby reducing water vapour migration through the film [Mohapatra *et al.,* 2010; Happi Emaga *et al.,* 2007].

The barrier properties of edible films are strongly influenced by polymer composition, molecular interactions, film thickness, moisture content, and the type and concentration of plasticizers [Siracusa , 2012, Pavlath *et al.,* 2009]. Therefore, the favourable WVP observed in the present study indicates the potential of the developed film for food packaging applications where moisture transfer needs to be controlled.

The oxygen transmission rate (OTR) of the developed banana peel and whole banana flour edible film was 5.264 cc/m^2/24 h. Oxygen barrier properties are important for food packaging because oxygen transmission can contribute to lipid oxidation, colour deterioration, nutrient loss, and quality deterioration in oxygen-sensitive foods [ASTM International, 2024, Robertson, 2013].

The observed OTR value indicates that the developed film possessed oxygen barrier properties. However, direct

comparison with commercially available packaging films should be made cautiously because OTR values depend on film thickness, temperature, relative humidity, and the specific test conditions used [ASTM International, 2024, Robertson, 2013].

The presence of glycerol may have contributed to improved flexibility and reduced brittleness of the film by acting as a plasticizer. Plasticizers generally increase polymer chain mobility and improve film flexibility; however, excessive amounts may increase gas permeability by increasing the free volume between polymer chains [Gontard *et al.,* 1993, Siracusa *et al.,* 2008]. The selected glycerol concentration in the present formulation appeared to provide adequate plasticization while maintaining acceptable oxygen barrier properties.

The FTIR spectra of the developed films revealed absorption bands characteristic of carbohydrates, dietary fibres, and other naturally occurring components of banana peel and whole banana flour. Only minor differences were observed among the spectra, which may be expected because of the similar composition of the film formulations.

The broad absorption band observed between 3000 and 3600 cm^{-1} was attributed primarily to the stretching vibrations of free and hydrogen-bonded hydroxyl (–OH) groups present in polysaccharides and other carbohydrate components [Kačuráková *et al.,* 2001, Poletto *et al.,* 2014; Bertuzzi *et al.,* 2007]. These hydroxyl groups are characteristic of starch, cellulose, pectin, and other polysaccharide-based materials.

The bands observed around 2930 and 2885 cm^{-1} were associated with C—H stretching vibrations of CH_2 groups. Absorption bands in the region of 2800–3000 cm^{-1} may be associated with aliphatic C–H groups present in polysaccharides, lipids, and lignocellulosic components [Kačuráková *et al.,* 2001, Poletto *et al.,* 2014; Bertuzzi *et al.,* 2007].

Several absorption bands observed between 1700 and 1200 cm^{-1} may be related to the presence of minor components such as proteins, lipids, pectin, and other functional groups present in the flour-based film matrix [Dadzie *et al.,* 1997; Sagar *et al.,* 2010, Debeaufort *et al.,* 2010]. The absorption band around 926 cm^{-1} may be associated with glycosidic linkages and structural characteristics of starch components, including amylose and amylopectin [Dadzie *et al.,* 1997; Sagar *et al.,* 2010].

The spectral characteristics therefore confirm the presence of carbohydrate-based and lignocellulosic components in the developed edible film. Similar FTIR absorption patterns have been reported for starch-, cellulose-, and banana-based biodegradable films [Mohapatra *et al.,* 2010; , Kačuráková *et al.,* 2001; Poletto *et al.,* 2014; Bertuzzi *et al.,* 2007].

The water solubility of the developed banana peel and whole banana flour edible film was 0.8%, indicating low solubility in water. Film solubility is an important property because it determines the stability and suitability of edible films for different food packaging applications [Pavlath *et al.,* 2009; , ASTM International, 2024].

The low solubility observed in the present study suggests the formation of a relatively stable polymeric network with strong intermolecular interactions among the components of banana peel and whole banana flour. The presence of cellulose, dietary fibre, and other structural polysaccharides may have contributed to the reduced dissolution of the film in water [Mohapatra *et al.,* 2010, Happi Emaga *et al.,* 2007].

Although glycerol is hydrophilic and can increase water affinity at higher concentrations, the relatively low concentration of glycerol used in the present formulation may have helped maintain the integrity of the polymeric matrix. Previous studies have demonstrated that the effect of glycerol on film solubility depends on its concentration and the interactions between the plasticizer and film-forming polymers [Gontard *et al.,* 1993; Siracusa *et al.,* 2012].

Therefore, the low solubility of the developed film may be advantageous for applications requiring resistance to moisture and maintenance of film integrity during food storage.

The microbiological analysis showed that the developed edible film was negative for the tested Enterobacteriaceae and Staphylococcus aureus. The absence of these microorganisms may be associated with the relatively low water activity (aw = 0.62) of the edible film.

Water activity is an important factor controlling microbial growth. Most bacteria require substantially higher water activity values for growth, whereas low water activity limits microbial metabolism and multiplication [Jay *et al.,* 2005; Pereira *et al.,* 2015]. Therefore, the low water activity of the developed film may have contributed to its microbiological stability.

The total aerobic mesophilic bacterial count was approximately 10^4 CFU/g. The presence of aerobic microorganisms may have resulted from environmental exposure during the preparation, drying, conditioning, or handling of the films because the casting procedure was not performed under completely sterile conditions.

The drying process can reduce the availability of water required for microbial growth and survival. In combination with low water activity, drying can therefore contribute to improved microbiological stability of food materials and packaging systems [Jay *et al.,* 2005; Pereira *et al.,* 2015].

These findings indicate that appropriate hygienic conditions during film preparation, drying, and conditioning is important for reducing the initial microbial load. Although information regarding the natural microflora of banana peel and pulp flour-based edible films remains limited, the present findings provide useful information concerning the microbiological quality and storage stability of the developed film.

The antimicrobial activity of the developed edible film was evaluated against *Enterococcus faecalis, Salmonella*

enterica, Escherichia coli, and Listeria monocytogenes. The film demonstrated antimicrobial activity against the tested microorganisms, indicating its potential application as an active edible packaging material.

The observed antimicrobial effect may be associated with naturally occurring bioactive compounds present in banana peel, particularly phenolic compounds and other antioxidant phytochemicals. Banana peel has been reported to contain phenolic compounds, flavonoids, tannins, and other bioactive constituents that may contribute to antioxidant and antimicrobial properties [Mohapatra *et al.,* 2010; , Stone *et al.,* 2012; Pereira *et al.,* 2015].

Phenolic compounds can affect microorganisms through several mechanisms, including disruption of cell membranes, interaction with cellular proteins and enzymes, and interference with essential metabolic processes [Stone *et al.,* 2012; Pereira *et al.,* 2015]. However, the antimicrobial activity of the film may vary depending on the concentration and availability of bioactive compounds, the type of microorganism, and the diffusion of antimicrobial substances from the film matrix.

Therefore, the antimicrobial activity observed in the present study supports the potential use of banana peel-based edible films as functional packaging materials. Further studies involving the identification and quantification of phenolic compounds and the determination of minimum inhibitory concentrations would provide additional information regarding the antimicrobial mechanism of the developed film.

4.1 Sensory analysis

The results of the sensory scores of the edible films are shown in the Figure 4.1

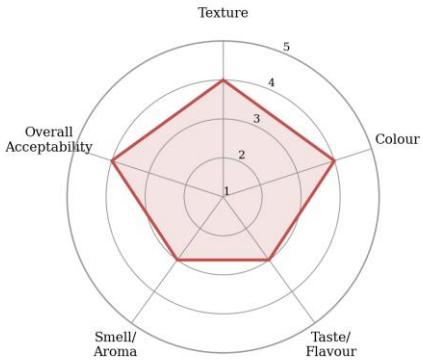


Fig 4.1: Sensorial evaluation of Edible film of Trail III

4.2 TRAILS OF FILMS

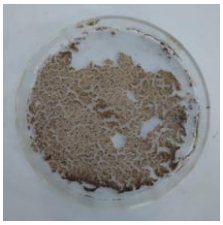


Fig 4.2 – Trail I



Fig 4.3 – Trail II



Fig 4.4 – Trail III

CONCLUSION

The combination of whole banana flour and banana peel flour exhibited good film-forming ability in the presence of glycerol as a plasticizer. The two chosen formulations showed little variation in their general characteristics. However, the F-1.5 G film showed a higher water absorption because of the higher hygroscopicity, and thus a higher film density, more compact structure and a smoother surface were obtained. The film with a lower concentration of glycerol (F-1.0 G) had a relatively rougher structure and was less elastic and deformable with increased rigidity compared to the standard. The developed films showed no significant antibacterial activity. Sensory evaluation revealed good overall acceptability for the three evaluated presentations including two different snack products. These results indicate that the incorporation of waste green bananas flours (whole banana flour and banana peel flour) to edible packaging systems could be a promising and sustainable alternative for food applications. The application of these banana processing by-products may contribute to waste valorization and the development of environmentally friendly and biodegradable food packaging materials.

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