DEVELOPMENT AND CHARACTERIZATION OF EDIBLE PAPER FROM DIFFERENT VEGETABLES: A NOVEL APPROACH TOWARDS BIODEGRADABLE AND SUSTAINABLE PRIMARY PACAKAGING

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Abstract
The plastic packaging is typically and widely used, that are non-biodegradable and cause environmental pollution and health risk it's essential to transform sustainable packaging. This project deals with critical situation and resolves issue by developing edible packaging paper it's a primary packaging derived from natural plant-based source. The primary objective is to utilize the fibrous components of cabbage (Brassica oleracea) and bottle gourd (Lagenaria siceraria), that are cheap, abundant, and rich in natural biopolymers like cellulose, pectin, and hemicellulose. The methodology involves extracting and processing the vegetable fibers, incorporating natural gums to enhance film-forming capabilities and using glycerol as a plasticizer to improve flexibility and mechanical strength. The anticipated results include the successful creation of a biodegradable and edible paper that provides a functional barrier to gases and moisture however, extending the shelf life of food products. The inherent bioactive compounds in cabbage and bottle gourd such as phenols and glucosinolates, are expected to impart natural antimicrobial and antioxidant properties to the packaging.

1.0 INTRODUCTION

1.1 Plastic problem:

As the packaging technology reduce waste chances by prevent food from contamination and enhancing its freshness but it also facing many challenges in extending shelf life of food products. One of most commonly used packaging material is plastic which is cheap and has good flexibility and durability. According to UNEP (United Nation Environment Program me) yearly about 400 million tons plastics are made and about 36% from them used for packaging purpose. But one of the main problems is that plastic not easily breakdown and remain in environment for hundreds of years. After years it breakdown into microplastics. which. cause. many. environmental problems, disturbs marine life and harm animals by polluting water and soil (Kumar et al., 2021). It also releases harmful residues when degrade. Current investigations reported microplastics in seafood, drinking water and even in human blood. This give rise to long term health effects because of these following issues we must have to move towards the eco-friendly, sustainable and biodegradable packaging (Lokesh Kumar, 2021) .One of the best option is edible packaging which can be consume with food, safe and biodegrade naturally without causing any harmful residues. It is not only ecofriendly but also elongate food freshness as it contains antimicrobial compounds.

Edible packaging or natural films are defined as thin, continuous and unbroken sheets that are extracted from plant and animals in the form of food grade biopolymers including protein, lipid and polysaccharide which make them eco-friendly and safe (S. K. Bharti, 2020). Edible packaging is not to completely replace the traditional packaging but it is to minimize the waste and increase protection of food by working together with traditional packaging.

1.2 Edible Packaging

Edible packaging includes films, coating, sheets and pouches to hold food. Coatings and films are used interchangeably but coatings are directly applied on surface of food while films stand-alone they first made, dry and then wrapped around the food (Orts, 2009).

Edible coating and films are used for centuries in order to prevent quality losses of meat and poultry products. In 15th century from soymilk the 1st edible film known as Yuba was made in Japan to preserve food. In 16th century fat was used by people of England to cover meat, then in 1967 edible coatings was limited to wax layer on fruits, in 1986little more than 10 companies offering such product and so on. Now today edible films are widely used and receiving importance.

These edible packaging are made to provide high quality food by providing barrier to gases, water, lipid and other contaminants. Enhance quality appearance like flavor, color and aroma migration. Provide structural integrity, prevent spoilage, increase shelf life and improve storage. The main advantage is that they can consume with food which reduce waste and if not consume they still help to reduce waste as they degrade more quickly as compared to other packaging material. They increase recyclability and can simplify packaging requirements. There are so many benefits but commercially its adaptation is still limited because of the following issues inability to produce continuous films, prolong drying time, high production cost and inaccurate thickness control. Lack of awareness on biodegradability, edibility, poor marketing, ignorance etc. cause impact on consumer acceptance (M.E., 2020). To make edible film commercially successful and industrial viable future research must be focus on these problems.

Biopolymers used in edible films are divided into 3 classes lipids(waxes, fats and fatty acids) , hydrocolloids(protein and polysaccharide) and composites (lipid + hydrocolloids) (Bourtoom, 2008).The selection of biopolymer depends on desired function of film like good barrier properties against oxygen, appearance, water loss etc. For edible coating most commonly polysaccharide based film is used which are derived from starch, pectin, alginate, carrageenans, chitosan, dextrin etc. They have good film forming properties , nontoxic and easily available, permeable to O_2 and CO_2 that slow down ripening and aging in fruits but they are hydrophilic because of this property they allow water to pass through which reduces shelf life of food by allowing microbes to grow (Janjarasskul, 2010).

To make edible packaging successful commercially this article focuses on making edible paper by utilizing vegetable derived fibers. Cabbage and Bottle guard are highly cultivated in many countries and are cheap and easily available. They naturally contain cellulose, hemicellulose, pectin and lignin which are natural film forming agents help to make paper more flexible and stronger. Cabbage and bottle guard contain some active compounds like phenols, ascorbic acid, glucosinolates, saponins, polyphenols, cucurbitacins etc. that play a major role in paper strength, antimicrobial activity and enhance shelf life.

This approach not only addressing plastic pollution but also promote the circular economy by converting vegetable and agricultural waste into value added product. This method helps in lowering the cost of raw materials, gives farmer a new source of revenue and provide food industry with better packaging option which is sustainable, biodegradable and safe.

Several researchers have developed edible films as shield against environmental harm, such as moisture loss, oxygen exposure, and microbial deterioration, by thin layers of edible material deposited as a film or coating. In order to lessen dependency on traditional plastic packaging and related environmental problems like chronic waste and pollution, these materials are made to be eaten with the food or to biodegrade harmlessly after usage (Janjarasskul et al., 2010).

By reducing the use and waste of synthetic plastic, edible packaging seeks to improve food shelf life, preserve quality, and support sustainability objectives.

Since Polysaccharides are abundant, biodegradable, and non-toxic. Polysaccharides like starch, cellulose derivatives, pectin, and chitosan are frequently utilized as the main film forming ingredients in edible packaging. For example, the potential of starch-based edible films to create flexible, biodegradable films appropriate for food packaging has been thoroughly investigated. Additives including glycerol, peanut oil, and lecithin have a substantial impact on water vapor permeability and other barrier qualities. According to research on cassava starch-based films, demonstrating how formulation influences performance for edible packaging regarding it's mechanical flexibility and moisture resistance are essential functional characteristics. According to experimental research, normal polysaccharide films have a tendency to be hydrophilic, which increases water vapor permeability (WVP) and decreases barrier effectiveness in humid environments. For instance, studies showed that the WVP of enhanced cassava starch films containing glycerol varied based on the amount of oil and plasticizer; some formulations achieved lower WVP than others, but this still highlighted the difficulty of moisture resistance in polysaccharide systems (Adjouman et al., 2024).

The hydrophilic nature of polysaccharides limits their application in moisture-sensitive food systems, as they tend to absorb water and exhibit poor water vapor barrier properties (Falguera et al., 2011).

The majority of polysaccharide-based edible films still have lesser moisture resistance than traditional plastic packaging, despite numerous studies showing increases in flexibility and mechanical strength through plasticization or mixing. Furthermore, a significant amount of current research uses refined or chemically modified polymers, which could raise production costs and decrease sustainability in general. Additionally, rather than paper-like structures that can offer improved mechanical integrity, the majority of research focuses on thin films and coatings.

The edible paper developed addresses a number of concerns found in earlier studies. The vegetable-based edible paper made from cabbage and bottle gourd uses naturally available cellulose, hemicellulose, and pectin fibers to generate a stronger fibrous network than traditional polysaccharide films, which are frequently fragile and moisture-sensitive. This structure preserves edibility and biodegradability while enhancing mechanical resistance and flexibility.

According to the studied literature, polysaccharide-based edible packaging still faces significant challenges in striking a balance between flexibility and moisture resistance. In comparison to numerous previously documented edible films, the current edible paper exhibits improved resilience and flexibility, indicating its promise as a practical and sustainable substitute for traditional plastic packaging materials.

For environmentally friendly food packaging applications, a number of researchers have created biodegradable edible films with starch-based materials. Glycerol and calcium carbonate were added to sweet potato starch to create biodegradable films (Otero Herrera et al., 25). According to their research, thickness, water solubility, and water vapor permeability were all strongly impacted by higher concentrations of starch and glycerol. Although the moisture barrier qualities were not as good as those of traditional plastics, the optimized film composition successfully preserved candies for 21 days without compromising their organoleptic qualities. Similarly, Zhang et al. (2024) used sweet potato starch combined with polyphenols derived from the peel to create an environmentally friendly edible film. The film's antibacterial, UV-blocking, and antioxidant qualities were greatly enhanced by the addition of polyphenols. The functional potential of bioactive starch-based films was highlighted by the extended shelf life, texture preservation, and decreased spoilage observed when applied to fresh fruits.

In this examine the use of sustainable and bioactive packaging film materials made from corn starch and whey protein with added transglutaminase enzyme and BLE. This purpose to investigate the functional ability of these packing materials in preserving Minas cheese.

Transglutaminase was an important component to enhance the strength of the films through the cross-linking mechanism involving whey proteins. This enzyme was crucial in boosting the mechanical strength of the films, which were rendered less water-soluble. Adding extracts from broccoli leaves was important for their bioactive properties, especially the antioxidant effect, which is vital for retarding the oxidation reaction prevalent in cheese.

Results showed an increased antioxidant capacity, darker appearance, and improved water vapor barrier in films containing broccoli extract. However, when transglutaminase was added, these properties improved further, making the films more protective in their capacity.

Few studies have examined the creation of edible films that use mixed vegetable purees as the main film-forming material, despite the fact that earlier research has shown the efficacy of starch-based and bioactive edible films made from sweet potato and broccoli by-products. Furthermore, a thorough assessment of the physicochemical characteristics, biodegradability, and shelf-life performance of these vegetable-based edible films is still lacking. As a result, the goal of this study is to create and describe an edible film made from vegetables and assess its potential for use and biodegradation as a sustainable packaging substitute.

As a sustainable substitute for traditional plastic-based primary food packaging, the main goal of this research is to create an edible and biodegradable paper using natural vegetable fibers from bottle gourds (Lagenaria siceraria) and cabbages (Brassica oleracea). The study's specific goal is to extract and use these vegetable fibers to make edible paper that has more flexibility and structural strength by adding natural plasticizers and stabilizers. The study also concentrates on assessing the proximate composition and physical properties of the produced edible paper. This includes the thickness, density, pH, swelling index, and oil permeability. In addition, the antioxidant and phytochemical composition of the edible paper is also assessed to determine its potential functional properties. Finally, the stability of the edible paper in terms of shelf life is also evaluated to determine its suitability for use in food packaging.

Methodology

Cleaning of Raw Material

washed by tap water and then peeled.

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Cutting Of cabbage & bottle guard

Peeled veggies are cutted into small slices.

↓

Soaking in Alkaline Solution

Sliced pieces of turnip are being soaked into alkaline solution of NaHCO, (baking soda) for about 30 minutes.

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Cooking
The soaked pieces are subjected to slight heating then are quickly cooled down under room temperature.

↓

Grinding
Slices are grinded into a grinder and formed into a thick liquor or paste like consistency.

↓

Stock Preparation
Add Xanthan gum. Guar gum, corn starch, CMC (carboxymethyl cellulose), and of glycerol in to slurry then mix it well.

↓

Sheet Forming
Pour the slurry over the aluminum foil and spread evenly that it would dry up into a sheet.

↓

Drying
After being left in controlled environment for 4-5 days, a paper like sheet appeared on the aluminum foil.

Testing

Estimation of fiber content

Acid and alkali digestion techniques were used to determine the amount of dietary fiber. Sulfuric acid (0.3 M), sodium hydroxide (0.3 M), a Soxhlet apparatus or round bottom flask, crucible dish, oven, muffle furnace, weighing balance, conical flask, filter papers, and volumetric flask were among the necessary tools and supplies. The solutions were prepared as follows: 14.7 g of sulfuric acid was precisely weighed and dissolved in distilled water to create a final volume of 500 ml in a volumetric flask for the 0.3 M H_2SO_4 solution. Likewise, 6 g of sodium hydroxide was dissolved.

About in 500 ml of distilled water to create the 0.3 M NaOH solution 20 to 25 grams of the sample were placed in a round-bottom flask, and 100 milliliters of 0.3 M H_2SO_4 were then added. A Soxhlet apparatus or a round-bottom flask with a condenser was used to boil the mixture for 30 minutes. The mixture was then cooled and filtered. Following treatment with 100 milliliters of 0.3 M NaOH solution, the residue was once more boiled for 30 minutes under the same circumstances. Boiling was followed by cooling, filtering, and collecting the residue in a crucible dish. To ascertain the dry residue, the residue was thoroughly cleaned, then baked for an hour at 80°C, cooled down and weighed. To finish the analysis, the crucible dish with the dry residue was lastly placed in a muffle furnace set to 400°C for an hour. In order to calculate the sample's overall fiber content, this procedure made sure that all soluble materials were eliminated, leaving only the insoluble dietary fiber.

Calculation:

% Fiber = {(wt. of dry residue - wt. of ash content) /wt. of sample} * 100

Determination of Moisture Content

The moisture content of the sample was determined using the conventional oven-drying method, based on the principle of gravimetric analysis (AOAC, 2005). This method involves the evaporation of water from the sample by applying a constant heat source (105°C). The loss in mass after drying is directly attributed to the moisture present in the sample. The result is expressed as a percentage of the initial mass of the sample. The moisture content of the sample was determined in triplicate using the standard gravimetric oven-drying method, as outlined by the Association of Official Analytical Chemists (Horwitz W et al., 2019). The procedure began with the preparation of clean, dry petri dishes, which were first dried in an oven at 105°C for one hour to eliminate residual moisture, then cooled in a desiccator and precisely weighed on an analytical balance. Approximately 5 grams of the representative sample was then accurately weighed into the pre-weighed petri dish. The loaded dish, with its lid removed, was placed in a mechanically convected oven maintained at a constant temperature of C for a period of five hours to ensure the complete evaporation of water. Following the drying process, the petri dish was transferred directly to a desiccator to cool to room temperature, preventing the hygroscopic dried sample from reabsorbing moisture from the atmosphere. The weight of the dish and the dried sample was recorded immediately after cooling. The moisture content, expressed as a percentage on a wet basis, was calculated from the weight loss using the formula:

Initial sample weight – Dried sample weight/ initial sample weight ×100

Swelling Index

Swelling index tells about film water absorption capacity. Small square piece of prepared edible film was cut first and dry in drying oven at 105°C for 1 hour to remove moisture. After drying the films was cooled at room temperature. Weight the film as initial dry weight. Now take a clean beaker and filled it with desired amount of distilled water. The sample was now immersed in distilled water for 5 minutes. After 5 minutes take out film carefully, remove surface moisture gently without squeezing and weight the film. Repeat the process for different time interval (10,15,20 minutes etc.) until weight of edible film become constant and note that weight as Wt. The swelling index was than calculated by the formula

$$\%SI = Wt. – Wo / Wo * 100$$

Where, Wt. is the equilibrium weight of swollen film and Wo is the initial dry weight of edible film

Thickness

The thickness of the edible paper samples was determined using a standardized digital thickness gauge (e.g., a micrometer or dial gauge) with a flat, circular presser foot and a constant applied pressure to ensure non-destructive and accurate measurement. To account for potential inherent variability and surface irregularities, the thickness was measured at a minimum of five randomly selected locations across the surface of each sample, ensuring that measurements were taken at a sufficient distance from the edges. The individual readings, recorded in millimeters (mm), were then averaged to calculate a single, representative mean thickness value for each sample. This procedure was performed in triplicate for each batch of edible paper to ensure the reliability and reproducibility of the results, and the final overall thickness is reported as the mean ± standard deviation of all replicate measurements (Bangar et al., 2021).

DPPH

For sample preparation, 1 gm sample, add 25ml of 99% methanol. Covered the sample and take water bath at room temperature. Preparation of DPPH solution, take 3.9mg DPPH powder in 100ml of 99% methanol, cover the sample and place it cool, dark and dry place for 2 hours. Centrifuge the prepared sample for 15 min at 6000 rpm. Filter the extract and store in conical flask. Prepare solution series of extract with methanol (0,2,4,6,8,10ml). Take 1ml of each solution, add 3ml DPPH solution, makeup by 99% methanol up to 10ml and store in a dark place for 30 min. Calculate absorbance of each sample by spectrophotometer at 517nm wavelength (Brand-Williams et al., 1995).

Total flavonoid content

Aluminum chloride colorimetric method was used by some advancement to determine the flavonoid content. Take 1ml sample mixed with 3ml of methanol, 0.2ml of 10% aluminum chloride, 0.2ml of 1M potassium acetate and 5.6ml of distilled water and keep it at room temperature for 30 minutes. Determine the absorbance at 420nm. Flavonoid content was determined from the standard curve and were expressed as quercetin equivalent (mg/gm) (Aiyegoro et al., 2010).

Total phenolic content

The amount of phenol in the edible paper extract was determined using the Folin-Ciocalteu reagent method, with certain modifications. 0.25 ml of Folin-Ciocalteu reagent and 0.75 ml of sodium carbonate solution were mixed with 0.05 ml of sample extract. The resultant mixture was incubated for 2 hours at room temperature. The sample's absorbance was measured at 765 nm. Gallic acid was employed as a standard. All tests were done in duplicate. The results were calculated using the standard curve and expressed as Gallic acid equivalents (mg/g of extracted substance) (Aiyegoro et al., 2010)

Result & discussion

The edible paper made from vegetable fiber showed acceptable physical, chemical and functional properties. The moisture % remain below 5% indicate good storage stability. The thickness of film (0.32 ± 0.03 mm) and density (1.13g/ml) showed that the film has strong stable structure suitable for handling and packaging. The paper has neutral pH slightly alkaline in nature suitable for food contact Presence of phenolics, flavonoids and tannins are confirmed by phytochemical analysis. The TPC (44.18 µg GAE/mL) and Total Flavonoid Content (1.78 mg QE/g) show significant antioxidant potential. DPPH assay indicates 47.41% radical scavenging activity. 6-8 months shelf life was studied which indicates no visible deterioration. Overall, the results support the potential of this vegetables fiber based edible paper as a sustainable and bioactive alternative to conventional packaging material.

Conclusion

To conclude the study, the applied claim of the edible paper as an efficient substitute for traditional cupcake inserts established incomparable adaptability and performance. During the baking process, the paper showed notable thermal stability, preserving its structural integrity, color, and phytochemical profile without roasting or humiliating under high temperatures. Dissimilar conservative butter paper, this vegetable-based alternative effortlessly combined with the cupcake, so long as sustainable, zero waste packaging solution that is totally consumable and disposable. This successful thermal trial proves that the bottle gourd and cabbage matrix is vigorous enough for high heat culinary applications, offering a twin advantage as both a heat-resistant baking medium and a nutrient boosted frosting that enriches the final product's texture and strength worth.

The long-term stability of the edible paper was assessed completely a shelf-life study which exposed an amazing strength of six to eight months underneath ambient storage conditions. During this observation period, the paper preserved its structural integrity and mechanical properties, screening only negligible variations in its physical state. This extended shelf-life is mainly attributed to the low water activity and the natural preservative assets of the tannins and phenolic compounds recognized in the cabbage and bottle gourd medium. Such high stability suggests that the product is resilient to rapid microbial spoilage and enzymatic browning, making it a highly viable candidate for commercial food packaging and long-term storage applications.

Moreover, the appealing and sensory assets of the paper precisely its texture and color continued strangely reliable over the eight-month duration. Although negligible variations in sort were noted, the paper did not become stiff or lose its characteristic flexibility, which is essential for its application as a cupcake liner or food wrap. This ability to retain its organoleptic properties without the need for synthetic preservatives emphasizes the success of the vegetable-based formulation. The combination of thermal stability during baking and high storage elasticity confirms that this edible paper is a vigorous, efficient, and sustainable alternative to conventional non edible liners offering significant potential for the zero-waste food industry.

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