

Development and Characterization of Corn and Potato Starch Based Intelligent Films with Anthocyanin from Eggplant Peels to Monitor PH Variations

Kanza Jamil^{*1}, Anum Liaquat, Nida Iqbal

Department of Food Science & Technology, Jinnah University for Women, Karachi, Pakistan

Abstract

In response to growing concerns over conventional plastic disposal, there is a pressing need for innovative biodegradable packaging solutions. In the current study, composite starch matrices made of potato and corn are mixed with eggplant peel extract to produce a unique bio-based packaging material. The main objective was to develop intelligent packaging that could assess food safety and quality and tell consumers of such information. Qualitative and quantitative analysis revealed ethanol as the most effective solvent for extract extraction. Physicochemical characterization of the resulting pH indicator film post-casting encompassed thickness, density, transparency, moisture content, water vapor permeability, water solubility, biodegradability, and antibacterial activity. Notably, the film exhibited rapid biodegradation within 14 days, along with robust antibacterial properties, evidenced by the absence of microbial growth. It also showed discernible color shifts in a variety of buffer solutions with pH values of 1, 4, 7, 9, and 12. Application trials demonstrated the efficacy of the intelligent film on diverse food items including cheese, chicken, potatoes, carrots, guavas, bananas, and tomatoes. These pH-sensitive packaging films hold promise as diagnostic tools for detecting food deterioration, owing to their sustainable manufacturing process and use of natural components.

Keywords: Corn, Potato, Starch, Eggplant Peels and PH Variations

*Address of Correspondence: Email: kanza.jamil1@gmail.com

Submitted on 12-11-2025– Revised on 13-12-2025– Accepted on 20-12-2025 Published on 4-1-26

INTRODUCTION

The need for food that is clean, nutritious, and has a longer shelf life in a safe state has increased due to changes in lifestyle and urbanization. Sustaining food standard is essential since it straightly contributes to the universal goal of enlightening the standard of living. To satisfy customer preferences, packaging must change from traditional to advanced and functionally enhanced (Farooqi et al., 2024). Historically, the main purpose

of packaging materials has been to act as passive, inert, and inactive barriers that keep contaminants, moisture, and air out of the food produce. This keeps the food's quality within a reasonable range and shields it from mechanical and chemical stresses. As new resources and creative methods to measure and report food quality in real time are developed, the functionality that can be integrated into packaging materials is growing at a very quick pace (Qamar, Sana,

Naveed, & Faizi, 2023). Active and intelligent packaging materials are two recent innovations that have helped create an effective food packaging system for safer and healthier food with the goal of enhancing food quality. One of the inventions of this field, which has been growing steadily, is smart packaging with a pH indicator. Food safety will be greatly enhanced by active and intelligent packaging, which will also improve food quality and reduce the need for food preservatives. By giving customers information on the quality and safety of the food through a range of signals, intelligent packaging aims to enable monitoring of the packed food and/or the surrounding environment (D. Naveed & Siddiqui, 2025; Sadia, Naveed, Rehman, Jamshed, & Dilshad, 2025; Siddiqui & Naveed, 2025).

In this context, the aim of the study was the development of film based on composite starch, potato and corn. The main objective was to produce intelligent packaging that could assess the food's quality and/or safety and relay that information to the customer. Anthocyanin are chemicals that can change color when they come into contact with different pH-value solutions. In order to facilitate the manufacture of starch-based intelligent film at a laboratory scale, a casting approach was chosen, a change in pH can be used to identify food deterioration events. Since pH reflect the condition of the product, so pH variations can therefore be used as indicators of food quality. Anthocyanin are among the natural pigments of plant origin, and because of their notable color shift at various pH levels, they hold tremendous

promise as indicators in intelligent packaging systems(Kaleem et al., 2025).

The primary by-products of eggplant fruit, eggplant peel and calyx, are mostly produced by industrial food processing units. These byproducts can provide significant amounts of anthocyanin and are easily utilized. The structure and concentration of numerous phenolic compounds found in eggplant were thoroughly studied, with a focus on flavonoids, which are primarily concentrated in the peel. The most prevalent phenolics in eggplant peel are called anthocyanin, which are a subtype of flavonoids. It has been tested that starch plays a significant role in biobased films. They serve as barriers that preserve quality and organoleptic qualities while inhibiting gas exchange, moisture transfer, solute movement, and oxidation. Improving the flexibility and durability of starch-based films is plasticizers' primary function. There were also effects on other qualities as biodegradation, water vapor permeability, and crystallinity(Qamar et al., 2023) .

MATERIALS AND METHODS

Procurement

Long purple eggplants (*Solanum melongena*), potato starch and corn starch were purchased from local market. Eggplants were sorted and washed. The peels were thinly sliced and stored in zip lock bags in the freezer for preservation in order to make the extract.

Preparation of eggplant peel extract

The frozen eggplant peels were thawed and weighed. Three stock solution were prepared comprising of aqueous ethanol, methanol and

aqueous methanol. The weighed peels were placed in amber bottles and stored in dark conditions for seven days.

After solvent extraction, each sample was heated for 1 hour under constant stirring. The sample was cooled and filtered. The filtered solutions were collected in separate beakers. Furthermore, Rotary Evaporator (TOPTION Brand, Model RE-5000, Jiangsu China) was employed for the separation of solvents from the extract at 60°C. The recovered extracts were collected in beakers, sealed properly and refrigerated (Sattar et al., 2025).

Proximate analysis

According to AOAC (2006), sample of eggplant peels were assessed for protein, ether extract, ash, total dietary fiber including soluble and insoluble dietary fiber. The eggplant peels were freeze dried for 72 hours, along with a lyophilizer, and then ground into a powder. After that, the powder was kept for analysis in polypropylene bags (Thangaraj, 2015).

Phytochemical analysis

Preliminary phytochemical tests were performed on hydro-alcoholic and alcoholic extracts of *Solanum melongena* fruit peels using standard methods. The carried out in vitro tests are documented below (Sadia et al., 2023; Siddiqui & Naveed, 2025):

Total phenolic content

The total phenolic content of eggplant peel extracts was evaluated using the Folin – Ciocalteu spectrophotometric assay. Take 0.5 mL of eggplant extract and was dissolved in deionized water. Add 0.25 mL of the Folin-

Ciocalteu reagent to the mixture. After incubating this mixture for a specific period, 20% Na₂CO₃ in 7.5 mL was added. After the blend was prepared, it was allowed to stand at room temperature in the absence of light for one hour. The absorbance of the mixture at 765 nm was then measured in comparison to a blank. The outcomes were reported in milligrams of Gallic acid equivalents per gram of dried out powder (Mehboob, Iftikhar, & Saify, 2025; S. Naveed, Rehman, Qamar, & Zainab, 2014).

Total anthocyanin content

In order to assess the total anthocyanin content of extracts obtained from eggplant peel, buffer solutions with concentrations of 0.4 M sodium acetate and 0.025 M potassium chloride at pH 4.5 and pH 1.0, respectively, were prepared, followed by weighing 0.93 g of KCl in a 1 L beaker. After adding 500 milliliters of distilled water, the mixture was thoroughly blended. After obtaining a measurement, the pH was adjusted by adding hydrochloric acid. 500 mL of distilled water was added to a 1-liter beaker containing 27.17 g of CH₃COONa.3H₂O. The pH was measured and adjusted to 4.5 by adding HCl. The rate of absorption was determined after 30 minutes at a wavelength of 520 nm and 700 nm.

Total flavonoid content

The total flavonoid content of the eggplant extracts was determined using the aluminum chloride spectrophotometric technique. After combining 0.25 mL of eggplant extract with distilled water and 0.075 mL of 5% NaNO₂ solution, the mixture was allowed to stand for five minutes. Subsequently, 0.15 mL of 10%

aluminum chloride solution was added. In addition, 0.5 mL of a 1 M sodium hydroxide (NaOH) solution was added, and deionized water was used to make up the solution to 3 mL. The absorbance of the mixture was measured at 510 nm against a blank. The findings were given milligrams of quercetin equivalents per gram of dried out powder

Antioxidant analysis

The free radical activity in eggplant peel extracts was assessed by 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method. In methanol, 0.1M solution of DPPH was prepared. The resultant solution, about 1 mL, was combined with the eggplant peel extract. It was vigorously shaken and allowed to rest for 30 minutes at ambient temperature. The absorbance of mixture was estimated at 517 nm (S. Naveed, Usman, Qamar, Sadia, & Muzafar; Turturică, Stănciuc, Bahrim, & Râpeanu, 2016).

Qualitative phytochemical screening

The evaluation of phytochemical content in *Solanum melongena* peel extracts was conducted using established procedures described by Jayaprakash and Sangeetha (Jayaprakash & Sangeetha, 2015).

Tannins test

In 0.5 mL 5% ferric chloride, 0.5 mL of the peel extract was added. The formation of greenish black or dark blue specifies the occurrence of tannins.

Flavonoids test

In 0.5 mL of the peel extract, 2N sodium hydroxide (0.5 mL) was added. The

development of yellow color signifies the presence of flavonoids.

Alkaloids test

Concentrated HCl about 1 mL and a few drops of Mayer's reagent were added to 0.5 mL of peel extract. Formation of white precipitate or green color show the existence of alkaloids

Glycosides test

The peel extract was added to 1.5 mL of a solution containing 5% ammonium and chloroform in increments of 0.5 mL. The appearance of a pink color represents the existence of glycosides.

Terpenoids test

In 0.5 mL of peel extract, 1 mL of chloroform was added. The resultant solution was mixed with concentrated sulfuric acid. The emergence of a reddish-brown color indicates the existence of terpenoids (Guimarães et al., 2019).

Phenols test

A relatively small amount of 10% ferric chloride was added to 0.5 mL of the peel extract along with 1 mL distilled water. The development of a blue-green color indicates the presence of phenol.

Anthocyanin and Betacyanin test

0.5 mL of 2 N NaOH was added to 0.5 mL of peel extract, and the mixture was heated to 100°C for 5 minutes. The onset of a blue-green color suggests the presence of anthocyanin. Conversely, the development of a yellow color signifies the presence of betacyanin.

Preparation of the film

Potato and corn starch based films were developed by solvent casting process. Concerning the formulation of the films, distilled water was added to starch and heated under constant stirring until gel-like solution was formed. After cooling, glycerol and extract were added. The film solution was further stirred for 5 minutes and casted on a Teflon coated plate and oven dried at 40°C for 24 hrs.

Characteristics of the film

Physiochemical testing was conducted on the films to examine both their physical and chemical properties, offering crucial insights into the composition, structure, and behavior of the substances. The characteristics of film is essential for ensuring quality, developing products, and continually enhancing manufacturing processes

Thickness of film

The film's thickness was measured by digital micrometer (Mitutoyo, Model IP 65, Japão) from 10 different sites and mean value was calculated (Hosseini et al., 2013).

Film density

The density of biodegradable packaging film was determined using the test method of ISO 1183 (ASTM D792). For this, a 25 ml RD bottle was used. The known film solution was added to the RD bottle, and it was weighed both ways (Hosseini et al., 2013).

Moisture content

The film sample's moisture content was determined by the gravimetric approach in an

oven (FCPO-150, Dongseo Science Ltd., Seongnam, Korea) at 105 C for 24 hours.

Solubility of film

Film sample was oven dried at 105°C for 1.5 hours and then weighed (Initial dried weight). For 6 hours, the dried films were kept at 25°C after being submerged in 50 mL of distilled water. After filtering the mixture, the film was dried at 110°C till it acquired a constant weight (final dried weight) as described by Hosseini et al. (Hosseini et al., 2013).

Water Vapor Permeability

The WVP of film was estimated using technique stated by Yong et al. (2019). In brief, a 50 mL centrifuge tube with 40 g of anhydrous silica gels was filled. After that, a film sample was placed to cover the tube, placed in a desiccator with 100% RH distilled water, and weighed every 24 hours for seven consecutive days.

Film Transparency

In order to evaluate the optical property of the film sample a piece of film was placed directly into the magnetic cells of the spectrophotometer (Single Beam UV-VIS Spectrophotometer with Scanning Software Model No: HV-291, Shimadzu, Kyoto Japan), with an empty test cell as a reference. The UV – screening and transparency of film in terms of percent transmittance was analyzed at wavelengths of 280 nm and 660 nm, respectively (Piñero et al., 2016).

Biodegradation Test

A weighed piece film sample was placed at a depth of 1-2 cm in plastic trays containing organic fertilizer made of vegetable wastes.

At room temperature under aerobic condition, the plastic trays were incubated. Later, film sample was recovered at 7 to 14 days of the test. The buried films were visually inspected to track the composting process, and samples were periodically removed and photos were taken to check the difference Piñeros et al., (Piñero et al., 2016).

Bio – activities assay

Bioactivities assay involved the examination of tendency of a packaging to engage with particular biological compounds or indicators. These assessments play a crucial role in verifying the packaging films efficiency in preserving and monitoring the state of the packaged product.

Antimicrobial activity

The film sample was divided into 1 cm by 1 cm sections, which were then put on agar plates (Saboraud Dextrose Agar for yeasts and Muller Hinton 2 for bacteria). Following an incubation period of 24 hours at 37°C, film sample was spread on agar plates. The amount of growth under and around the control film was compared to the amount of growth under and around the microorganisms on the film to visually interpret the results(S. Naveed, Hameed, Sharif, Urooj, & Mehak, 2014).

The pH sensitivity of film

The pH sensitivity of the film was measured by submersing pieces of film sample in various ranges of buffer solutions at different pH values (1, 4, 7, 9 and 12) for 5 minutes. After the immersion, any observable color shifts in the film sample were captured using a digital or smart phone camera.

Application test

To ensure that the color indication was credible, pieces of prepared intelligent packaging film were placed on a variety of products, including fruits, meats, dairy products, and vegetables. Each product was covered by a film sample, which was stored at a suitable temperature and occasionally checked for up to seven days. Since, fruits, vegetables, and milk-based products release organic acids as they deteriorate the formation of nitrogenous compounds in meat and seafood items is thought to be the cause of the higher pH(Piñero et al., 2016).

Statistical analysis

The mean values $\pm$ SD of the present investigation were utilized to illustrate the results. All measurements were taken in triplicate. The statistical analysis was conducted using Statistix version 9.0. To compare the means at $p < 0.05$, an analysis of variance (ANOVA) through Tukey's multiple range tests was used.

RESULTS AND DISCUSSION

Proximate analysis

The outcomes of the proximate analysis of eggplant peel (Table 3.1) showed that the moisture content was higher than the results of moisture reported by Hussain et al. (2011), with a range of 9.15 to 9.45% alongside with the existence of 12.25% protein. The assessment of dietary fiber revealed that the peels of an eggplant contains 43.31% total dietary fiber along with 1.52% ether extract fat content 6.20% ash content. Even so, the current study's outcomes agreed with those of

due to their significantly higher concentrations of anthocyanin than grapes, eggplant cultivars with dark purple skin gain a lot more attention than grape varieties. Because of its high level of insoluble dietary fiber, vitamins, minerals, and bioactive compounds, eggplant is regarded as one of the healthiest vegetables in terms of nutritional value. It also has a relatively low calorie value

Phytochemical analysis

Total phenolic content

The current study highlighted the total phenolic content of the hydro ethanol 39.40 ± 0.01 mg GAE/100g DE, hydro methanol 26.62 ± 0.01 mg GAE/100g DE and ethanol extract 55.55 ± 0.38 GAE/100g DE extracts which revealed noteworthy difference ($p < 0.05$) as shown in Table 3.2. The phenolic content evaluated of the eggplant peel extracts in the current study had the mean square value of 315.525mg GAE/100g DE. In a study conducted by Jung et al. (2011), it is reported 55.19 ± 1.3 mg GAE/100g DE in 70% of ethanolic extract in peels of eggplant which is in correspondence to the current study. In another research conducted by Todaro et al. (Todaro, Bonanno, & Scatassa, 2014) who investigated that fresh eggplant peels' acidified ethanol extract had a phenolic concentration of 188.73 ± 73 g GAE/mL of extract; these values are substantially greater than those found in the recent research. This significant distinction could arise from variations in the types of fruit peels involved.

Total anthocyanin content

The majority class in eggplant peel is made up of anthocyanin, which are well-known for their strong antioxidant properties. Thus, effective extraction techniques are required. Aqueous methanol, aqueous ethanol, and ethanol extracts are the three anthocyanin extracts which differ significantly ($p < 0.05$) as shown in Table 3.2. The values are approximately 82.80 ± 0.04 , 62.89 ± 0.05 , and 86.87 ± 0.28 mg of delphinidin-3-glucoside equivalent/100 g, respectively. Todaro et al. (2009) found that using acidified ethanol as a solvent resulted in 76.44 ± 3.82 mg of delphinidin-3-rutinoside equivalent/100 g of peel. The results for the extracts of acetone, methanol, and ethanol were 51.56 ± 4.87 , 82.83 ± 1.07 mg DGE / 100 g d.w., and 62.92 ± 0.15 mg DGE / 100 g d.w., respectively. The present assessment yielded comparable findings. The major anthocyanin in eggplants' peel, according to Horincar et al. (2020), are petunidin, delphinidin-3-glucoside, delphinidin3-glucosyl-rhamnoside, and delphinidin-3-(p-coumaroyl)-rutinoside-5-glucoside (nasunin).

Total flavonoid content

The findings of the total flavonoid content of the current study highlighted that hydro ethanol contained 4.48 ± 0.008 mg QE/100g DE, hydro methanol contained 16.28 ± 0.04 mg QE/100g DE and ethanol extract showed existence of 6.29 ± 0.21 mg QE/100g DE amount as depicted in Table 3.2. The results of Boulekbache et al. (2013) showed highest level of flavonoid detection in acetone extract 18.52 ± 0.07 mg QE/100 g DE, followed by methanol and ethanol extracts 16.26 ± 0.26

and 16.13 ± 0.12 mg QE/100 g DE, respectively which is in contrast to the recent study. In another study, Jung et al. (2011) have projected the total flavonoid content in 70% ethanol of eggplants' peel is about 6.19 ± 0.28 mg catechin equivalent/100 g DE. In a research conducted by Condurache et al. (2019), using the ultrasound assisted extraction method from dried eggplant peels, depicted a total flavonoid content of 4.48 ± 0.80 mg CE/g dw which is similar to the current study performed on the hydro ethanol extract.

Antioxidant analysis

The findings of current research was based on the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) assay to assess the antioxidant capacity of each eggplant peel extract. Table 3.2 shows that there is a significant difference ($p < 0.05$) in the antioxidant capabilities of the three eggplant peel extracts that were evaluated in the current study: aqueous ethanol, aqueous methanol, and ethanol. 39.66 ± 0.04 , 63.03 ± 0.12 , and 87.26 ± 0.209 are the respective mean values. According to Cui et al. (2021), the additional vital the antioxidant activity of film composed of starch makes them useful as food packaging materials. The anti-oxidation capabilities of starch containing films are enhanced by the inclusion of antioxidant compounds, hence prolonging the shelf life of packaged goods.

These results revealed that, in comparison to the other two extracts, the ethanolic extract exhibited a greater potential for antioxidant or free radical scavenging activity. Following this approach, the solution's color would change from dark purple to pale yellow as the

DPPH free radicals were scavenged by the sample, causing DPPH to convert back into its non-radical form. This observation was aligned with the research conducted by Elleta et al. (2017) and Kazemi et al. (2019). Conversely, the scavenging ability of chitosan film was much decreased ($p < 0.05$). The amino groups at chitosan's C-2 position have the potential to scavenge free radicals, which is primarily responsible for the film's antioxidant properties.

Qualitative phytochemical screening

The findings of the phytochemical screening of extracts from eggplant peels revealed that the ethanolic extract had high concentration of flavonoids, anthocyanin, phenols, tannins, terpenoids, and alkaloids, whereas betacyanin was not present. It was clear that tannins, terpenoids, phenols, flavonoids, betacyanin, and glycosides were present in the hydromethanolic peel extract. However, no evidence of alkaloids or anthocyanin was found. Though, in the hydroethanolic peel extract alkaloids, tannins, terpenoids, phenols, flavonoids, anthocyanin, betacyanin, and glycosides were present. Table 3.3 presents the assessment of phytochemical constituents in extracts based on the results of a qualitative phytochemical screening. The current findings are analogous with those of Jayaprakash and Sangeetha (2015), who assessed the phytochemical components in pomegranate peel extract.

Characteristics of the film Thickness of film

The thickness of food packaging films is an important aspect as it directly impacts various physical properties such as tensile strength

(TS), water vapor permeability (WVP), and transparency, as indicated by Wang et al. (2019). The reported film thickness was 15.03 ± 0.81 mm, as shown in Table 3.4. Studies by Musso et al. (2016) and Chen et al. (2021) have shown that flow characteristics, dispersibility, and film composition all have a major impact on this parameter. The concentrations of starch, glycerol, and anthocyanin determine the film's thickness; an increase in these components' levels causes the film's thickness to increase accordingly.

Zhang et al. (Zu et al., 2020) used starch/polyvinyl alcohol to construct pH-sensitive films and added purple sweet potato anthocyanin at two different loadings. When anthocyanin was incorporated at a 0.5% concentration, there was an increase in film thickness from 64 μm to 71.6 μm , and at a 1% concentration, to 97.7 μm . Higher anthocyanin levels have been shown to enhance the film-forming matrix's complexity, which could result in an increased film thickness. Differences in film thickness reported in the current investigation compared to prior findings could be related to changes in anthocyanin compositions and concentrations in the extracts. Comparable results were seen by edible films made from modified potato starch, where an increase in thickness was linked to an increase in the solution's total solids content. For instance, thickness increased from 0.13 to 0.15 mm with a 50% increase in starch concentration. These findings are consistent with the present evaluation. Nonetheless, changes in the amylopectin concentration of the two starches may account for the thickness

difference seen in the corn and potato starch pH indicator film when compared to these studies.

Film density

Based on the present study, Table 3.4 indicates that the density of intelligent film was 2.16 ± 0.81 g/cm³. According to, the filler or additives introduced to the starch matrix determine whether the density of the biofilm increases or decreases observed a decrease in density when using plasticizer reported a boost in the density of biofilm generated with the addition of nanoclay. It is reported that the density of films made from a blend of low density polyethylene and starch ranged from 0.935 to 1.195 g/cm³. The findings showed that when more and more dense starch was introduced into the LDPE matrix, the density values increased in correlation with the starch content in the blend.

Moisture content

The moisture content of the composite starch – based intelligent film under this study, composed of anthocyanin extract, was found to be $7.5 \pm 0.29\%$ as depicted in Table 3.4. Zhu et al. (Owen et al., 2021) stated that the moisture content of their intelligent pH sensitive film, which was composed of cassava starch/polyvinyl alcohol and anthocyanin extracts, ranged from 11.07% to 13.93%. In contrast, our investigation showed a decreased moisture content. Nonetheless, presented the claim that moisture was decreased and the connections between the hydrophilic hydroxyl groups in starch were minimized. This could be because anthocyanin was added, which

altered the way that starch and water interacted (Owen et al., 2021).

Moisture content is the total free volume that water molecules occupy in the film network. The present study's findings, however, are dependable with the results of previous findings which defined the phenomenon responsible for the decreased films' moisture content. Specifically, the study expressed that the moisture contents of starch/polyvinyl alcohol-roselle anthocyanin films considerably decreased as anthocyanin content increased.

Solubility of film

The current study's results show that biodegradable pH indicator packaging film induced with anthocyanin had a water solubility of $55.06 \pm 0.15\%$ (Table 3.4). The assessed outputs are at contrast with those of, who found that a purple sweet potato starch and peel-based film with 2% anthocyanin had $57.26 \pm 2.88\%$ solubility and in the presence of 1% anthocyanin had a water solubility of $60.58 \pm 7.24\%$. Although, the results of current study are in distinction with the study conducted by that highlight the possible reason that the crosslinking and stronger molecular connection among anthocyanin and starch caused the indicator films to be less soluble in water than the starch film. Water solubility is a key attribute for intelligent films due to the water-attracting nature of bio based films. The produced films' water resistance and barrier qualities are shown by their water solubility. The films' water solubility is necessary for its use. Since it limits the use of watery food, higher water solubility is not preferred for packaging .

Water vapor permeability

The water vapor permeability of the intelligent film composed of composite starch and anthocyanin extract, which was determined to be $5.201 \pm 0.81 \text{ g mm/m}^2 \text{ day}^{-1} \text{ kPa}^{-1}$ as displayed in Table 3.4. The results of the current research were lower than those of, examined a rich starch/glycerol based film including antioxidants and found that the water vapor permeability was $9.31 \pm 0.10 \cdot 10^{-11} \text{ gm}^{-1} \text{ s}^{-1} \text{ pa}^{-1}$. The evaluated results, however, exceeded those of Araújo et al. (2015), who discovered that the water vapor permeability of biodegradable packaging film with 1% ethanolic propolis was $2.95 \pm 0.32 \text{ g day}^{-1} \text{ m}^{-1} \text{ Pa}^{-1}$.

Similarly, found that the pH-sensitive film containing extracts of purple and black rice had water vapor permeability of $5.35 \pm 0.34 \cdot 10^{-11} \text{ gm}^{-1} \text{ s}^{-1} \text{ pa}^{-1}$. Despite this, the results of this research were analogous to their findings. The current study's findings, however, were not in accordance with those of, who developed starch- and chitosan-based intelligent films containing eggplant anthocyanin.

Film transparency

Table 3.4 displays both the transparency of the film and the light transmittance at the UV region. The film absorbed more than 99% of the UV radiation and only transmitted less than 1% of it. Higher UV-screening ability is indicated by reduced film transmittance at UV light (280 nm). The film's transparency was found to be $73.86 \pm 0.24\%$. The greater the film's transmittance value, the greater will be its transparency, because greater amounts

of light (660 nm) can travel through it. The current study produced similar results, with the film displaying increased transparency. It was analyzed transparent nano-cellulose hybrid films containing ZnO nanostructures for UV-blocking, emphasizing their elevated UV absorption and reduced visible light absorption, which resulted in effective UV-blocking and apparent light transparency. The present study yielded comparable outcomes, with the film exhibiting significant UV absorption. Studies conducted by Saffert indicate that milk fat can be effectively protected against photo oxidation by reducing light transmittance by around 10-15%, preferably less than 10%, at 450 nm.

screening and water vapor permeability of ethanol extract film.

Biodegradation test

Table 3.5 shows the biodisintegration progression for edible films buried in solid composting material. Degradation was evident during the first three days of the experiment, as evidenced by the color and structural integrity of the film changing noticeably. Past research has shown that the enzymatic activity of microbes, heat, and moisture work together to promote the disintegration and weakening of starch polymer chains. The majority of the film decomposed throughout the 14-day trial period. Similar outcomes were noted in the study by Laxmeshwar et al. (Laxmeshwar et al., 2018), regarding cellulose fiber-reinforced poly (vinyl alcohol) films. The films produced in this work have good biodegradation properties, which may help with the ongoing issues with accumulation

and non-degradation caused by petroleum-based plastics. According to biodegradable polymers can decompose, mostly by enzymatic means, or decompose into inorganic chemicals, methane, carbon dioxide, or water over a specified period of time.

Bioactivities assay

Antimicrobial activity

The films' antimicrobial activity against yeast and bacteria was evaluated, and the results showed promising outcomes. On the agar plates, no bacterial or fungal development was seen. However, the film samples clearly showed structural modification and loss of integrity. The added anthocyanin and higher concentration of phenolic compounds in the film are probably responsible for the increased antibacterial efficacy. Corn starch films showed antibacterial action against *Staphylococcus aureus* and *Escherichia coli*, according to research by Bagde and Nadanathangam, (2019). Films containing bacteriocins showed the maximum activity against bacteria, whereas those containing crystalline nano cellulose (CNC) derived from cotton linters showed the lowest activity. Specifically, compared to films without bacteriocins, the presence of BIN in the films resulted in a reduction of bacterial activity against microorganisms of up to 17%. Similar results were obtained in terms of suppressing microorganisms from the current evaluation. By adding RPPE to chitosan-starch films improved their antibacterial efficacy against a variety of fungi, such as *Aspergillus fumigatus*, *Aspergillus niger*, and

Penicillium notatum, as well as *Escherichia coli*.

The pH sensitivity of film

Film samples showed a pinkish color when immersed in highly acidic pH buffer (1). At pH 4, the pink color of film faded, that is, it became light peach. The color of film remained unchanged at neutral pH level (7). Followed by basic pH level (9), the color of film changed to dull peach and then film became greenish at higher pH level (12). The visible color changes of film are shown in Figure 4.1 and 4.2. The resultant color responses of intelligent film were in contrast with the findings of formulated starch and chitosan based intelligent film using anthocyanin from eggplant peels. Such that, at acidic pH values (2–6), film samples began to appear reddish, while at higher pH levels (7–10), films turned blue green. The pH indicator film displayed a distinct molecular structure in the solution due to the buffer solution's varied pH, which resulted in a different color .

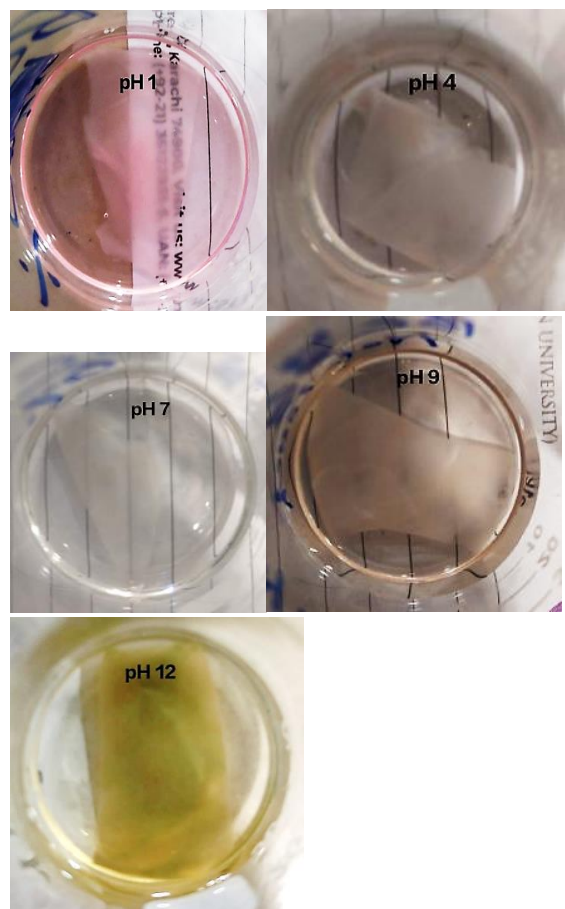


Figure 1. Visual appearance of films containing eggplant peel extract after immersion in buffer solutions with different pH values



Figure 2. Color response of composite starch-based film samples containing eggplant peel extract in different pH buffers

Application test

The pH-sensitive films were utilized to monitor the deterioration of several commodities, especially fruits (guava, tomato, banana), vegetables (carrot, potato), dairy items (cheese), and meat (chicken). The films were applied to the upper surface of the products. Noticeable color shifts were seen in the films, as Table 3.6 displays. A biosensor mat composed of electrospun nanofibers was produced using polyvinyl alcohol and RCE ACN. This study set out to evaluate the freshness of a particular kind of fresh date fruit called Rutab. The goal of the study was to assess fruit quality by measuring the sourness brought on by microbial development. The date fruit was fresh when it was first harvested, with a typical pH of 6.75 to 6.90. But after three days at 25°C, microbial growth took place, causing the fruit's pH to drop and its color to shift from violet to purple. The development of a smart color indicator film with chitosan, *Melissa officinalis* essences, and pomegranate peel extract was demonstrated in the work by scientist. According to their research, adding pomegranate peel extract improved tensile strength, lowered elongation at break, decreased moisture loss, and decreased water vapor permeability. In addition, they noticed that as the pH changed from 2 to 5, the film's color shifted from red to blue. According to the current study's findings, starch-based films containing anthocyanin extracted from eggplant peels might find similar uses, especially when it comes to cheese. It used a smart film enhanced with red grape and blueberry skin pomace, chitosan, and carboxymethyl cellulose to test the freshness

of chicken flesh. After 48 hours of fresh storage, the researchers found that the pH of the chicken meat rose from 5.9 to 6.5 and that there was a discernible shift in the color of the film indicator. Comparably positive results were obtained with the current assessment for the color indication.

CONCLUSION

The production of synthetic, non-biodegradable packaging film poses a hazard to the ecology. In order to combat the prevalent concern, the production of biodegradable film by using biopolymer along with the incorporation of bioactive – colorant compound is encouraged. To fulfill the present era's demand, researchers are focusing to develop pH indicator intelligent packaging film induced with naturally occurring pigment. In this regard, anthocyanin is a significant source of a natural color compound which imparts tendency to film to transform its color in response to pH alteration such that deterioration of food commodity is evident visually. The perspective of present investigation was to explore the color changing ability of pH indicator film by incorporating anthocyanin to facilitate the production of such packaging that might not serve as a potential harm to the environment. For this purpose, food waste was considered as a promising source to be utilized for extraction of color compound.

The presence of anthocyanin rich films frequently results in changes to their physical properties, such as, water-solubility, thermal stability, moisture content, water vapor

barrier ability, thickness, mechanical property and color. These changes are caused by intermolecular interactions, such as electrostatic relations and hydrogen bonds, among the anthocyanin and the matrix of film. The investigated films have exceptional pH-sensitive qualities along with antioxidant and antibacterial properties because of the included anthocyanin – rich extracts. The development of films comprising of multiple starch is particularly competent, since only starch containing films often exhibit

restricted barrier and mechanical potential. Additionally, nanomaterial as a reinforcing compound can be added to anthocyanin – containing films to progress their functional characteristics even more. Conclusively, furthermore work can be done on the anthocyanin starch based intelligent packaging created such as tensile strength, mechanical properties, color, extract consistency and application on liquid products.

Table 1. Proximate composition of eggplant peels

Components	Composition (%)
Moisture (dry content)	9.17 ± 0.02
Crude Protein	12.7 ± 0.17
Total dietary fiber	40.30 ± 0.02
Soluble dietary fiber	12.05 ± 0.01
Insoluble dietary fiber	28.25 ± 0.02
Crude Fat (ether extract)	1.54 ± 0.02
Ash	6.4 ± 0.17
Carbohydrate	29.89 ± 0.016

Table 2. Table for mean value of Total phenolic content, Total flavonoid content, Total anthocyanin content, Antioxidant activity (DPPH)

SAMPLE	TPC (mg GAE/ 100g DE)	TFC (mg QE/ 100g DE)	TAC (mg D3G/100g)	DPPH (%)
Hydroethanol	39.40±0.01 ^b	4.48±0.008 ^c	62.89±0.05 ^c	39.66±0.04 ^c
Hydromethanol	26.62±0.01 ^c	16.28±0.04 ^a	82.80±0.04 ^b	63.03±0.12 ^b
Ethanol	55.55±0.38 ^a	6.29±0.21 ^b	86.87±0.28 ^a	87.26±0.209 ^a

Table 3. Phytochemical screening of eggplant peel extracts

Phytochemical constituents	Hydromethanolic extract	Ethanolic extract	Hydroethanolic extract	Name of the test
Alkaloids	-	+	++	Mayer's test
Tannins	+	++	+++	Ferric chloride test
Terpenoids	++	++	++	Salkowski test
Phenols	+	+++	++	Ferric chloride test
Flavonoids	+	++	++	Alkaline reagent test
Anthocyanin	-	+++	+	Alkaline reagent test
Betacyanin	+	-	+	Alkaline reagent test
Glycosides	+	++	+++	Keller killiani test

- (Absent); + (Fair amount); ++ (Moderate amount); +++ (High amount) *Values are expressed as mean $\pm$ standard deviation. The mean values in the same column of the table with different superscript letters (a, b, and c) indicate significant differences in Tukey's test at $p \leq 0.05$.

Table 4. Thicknesses, moisture contents, water solubility, density, transparency, UV

Film	Thickness (mm)	Moisture Content (%)	Water solubility (%)	Film Density (gm/cm ³)	Film Transparency (%)	UV Screening (%)	Water vapor permeability
							(g mm/m ² day ⁻¹ kPa ⁻¹)
Ethanol extract film	15.03 $\pm$ 0.81	7.5 $\pm$ 0.29	55.06 $\pm$ 0.15	2.16 $\pm$ 0.81	73.86 $\pm$ 0.24	0.57 $\pm$ 0.05	5.201 $\pm$ 0.81

Table 5. Visual appearance of edible films recovered at different composting times

SYSTEM	Composting times		
	Initial time	3 days	14 days
Ethanol extract film			

REFERENCES

- Farooqi, S. S., Naveed, S., Qamar, F., Sana, A., Farooqi, S. H., Sabir, N., . . . Sadia, H. (2024). Phytochemical analysis, GC-MS characterization and antioxidant activity of *Hordeum vulgare* seed extracts. *Heliyon*, 10(6).
- Guimarães, A. C., Meireles, L. M., Lemos, M. F., Guimarães, M. C. C., Endringer, D. C., Fronza, M., & Scherer, R. (2019). Antibacterial activity of terpenes and terpenoids present in essential oils. *Molecules*, 24(13), 2471.
- Hosseini, S., Urbanski, S. P., Dixit, P., Qi, L., Burling, I. R., Yokelson, R. J., . . . Weise, D. R. (2013). Laboratory characterization of PM emissions from combustion of wildland biomass fuels. *Journal of Geophysical Research: Atmospheres*, 118(17), 9914-9929.
- Jayaprakash, A., & Sangeetha, R. (2015). Phytochemical screening of *Punica granatum* Linn. peel extracts. *Journal of academia and industrial research*, 4(5), 160-162.
- Kaleem, A., Sana, A., Khan, R. U., Naveed, S., Qamar, F., Zainab, S., . . . Sathian, B. (2025). Next-gen ferulic acid-stabilized gold nanoparticles: exploring their sensing capabilities and therapeutic efficacy. *Therapeutic Delivery*, 16(5), 447-457.
- Laxmeshwar, L. S., Jadhav, M. S., Akki, J. F., Raikar, P., Kumar, J., Mahakud, R., & Raikar, U. (2018). Quantification of chloride and iron in sugar factory effluent using long period fiber grating chemical sensor. *Sensors and Actuators B: Chemical*, 258, 850-856.
- Mehboob, S., Iftikhar, J., & Saify, Z. S. (2025). *Zoo Botanica*.
- Naveed, D., & Siddiqui, U. N. (2025). Hyaluronic Acid: Nature's Versatile Biopolymer for Health, Healing, and Beauty. *International Journal of Trends in Health Sciences*, 3(1).
- Naveed, S., Hameed, A., Sharif, N., Urooj, A., & Mehak, R. (2014). Use of 3rd generation cephalosporins in different age groups in tertiary health care centers of Karachi. *Journal of Scientific and Innovative Research*, 3(2), 1-4.
- Naveed, S., Rehman, H., Qamar, F., & Zainab, S. (2014). Method development and validation of Vildagliptin using UV spectrophotometer. *Int J Pharm Sci Res*, 5(10), 714-717.
- Naveed, S., Usman, R., Qamar, F., Sadia, H., & Muzafar, W. Facile Synthesis of Silver Nanoparticle by Using Ferulic Acid and its Potential Pharmaceutical Applications.
- Owen, D. R., Allerton, C. M., Anderson, A. S., Aschenbrenner, L., Avery, M., Berritt, S., . . . Coffman, K. J. (2021). An oral SARS-CoV-2 Mpro inhibitor clinical candidate for the treatment of COVID-19. *Science*, 374(6575), 1586-1593.
- Piñero, J., Bravo, À., Queralt-Rosinach, N., Gutiérrez-Sacristán, A., Deu-Pons, J., Centeno, E., . . . Furlong, L. I. (2016). DisGeNET: a comprehensive platform integrating information on human disease-associated genes and variants. *Nucleic acids research*, gkw943.
- Qamar, F., Sana, A., Naveed, S., & Faizi, S. (2023). Phytochemical characterization, antioxidant activity and antihypertensive evaluation of *Ocimum basilicum* L. in I-NAME induced hypertensive rats and its correlation analysis. *Heliyon*, 9(4).
- Sadia, H., Naveed, S., Rehman, H., Jamshed, S., & Dilshad, H. (2025). Enhancing medication appropriateness: Insights from the STOPP (Screening Tool of Older Persons' Prescriptions) criteria version 3 on prescribing practices among the older adults in Pakistan. *Frontiers in Pharmacology*, 16, 1551819.
- Sadia, H., Naveed, S., Rehman, H., Usman, R., Qamar, F., Yasmeen, S., . . . Razzaq, G. (2023). Toxicity profiling and

- antihyperuricemic activity of Goubion: a polyherbal formulation. *Evidence-Based Complementary and Alternative Medicine*, 2023(1), 7088628.
- Sattar, A., Rehman, H., Naveed, S., Khadim, S., Khan, N., Kazi, A. F., . . . Jamshed, S. (2025). Trustworthiness of Web-Based Pharmacy Apps in Pakistan Based on the Mobile App Rating Scale: Content Analysis and Quality Evaluation. *JMIR mHealth and uHealth*, 13(1), e59884.
- Siddiqui, U. N., & Naveed, D. (2025). Nature's forgotten emulsifier: revisiting the chemistry, application and use of Gum acacia. *International Journal of Trends in Pharmaceutical and Chemical Research*, 3(1).
- Thangaraj, P. (2015). Proximate composition analysis. In *Pharmacological assays of plant-based natural products* (pp. 21-31): Springer.
- Todaro, M., Bonanno, A., & Scatassa, M. L. (2014). The quality of Valle del Belice sheep's milk and cheese produced in the hot summer season in Sicily. *Dairy Science & Technology*, 94(3), 225-239.
- Turturică, M., Stănciuc, N., Bahrim, G., & Râpeanu, G. (2016). Effect of thermal treatment on phenolic compounds from plum (*Prunus domestica*) extracts—A kinetic study. *Journal of Food Engineering*, 171, 200-207.
- Zu, Z. Y., Jiang, M. D., Xu, P. P., Chen, W., Ni, Q. Q., Lu, G. M., & Zhang, L. J. (2020). Coronavirus disease 2019 (COVID-19): a perspective from China. *Radiology*, 296(2), E15-E25.