

Development and Characterization of Intelligent Packaging Film to Monitor the Freshness of Fish

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Abstract

This research focuses on creating an intelligent packaging system using gelatin and chitosan and incorporating anthocyanins from purple cabbage, eggplant peel, and black currant as color indicators. The film developed aim to monitor fish spoilage and freshness in real time, utilizing anthocyanin sensitivity to pH changes as a visual indication. The study reveals that as anthocyanin concentration increases, film thickness and viscosity rise significantly. Transparency remains above 75%, ensuring clear visibility and effective color indication. Water vapor permeability decreases with concentration, ranging from $2.03 \pm 0.08 \text{ g/m}^2$ to $6.69 \pm 0.09 \text{ g/m}^2$. Anthocyanin-based pH indicators exhibit color changes, with the highest pH observed on the 7th day. The color changes observed were pink spots at acidic pH, mustard orange color at neutral pH and dark green spots at slightly basic pH. Porosity increases with concentration, ranging from $0.19 \pm 0.04\%$ to $0.40 \pm 0.04\%$. Overall, these films, particularly the CGA-EPP based film shows greater efficiency as eggplant peel consist of higher anthocyanin content compared to other two sources. This proves film to be beneficial for the food industry, offering a quick and cost-effective method for determining fish spoilage and freshness through color indication and minimizing the need for further testing.

Keywords: Intelligent film. Packaging film. Anthocyanin. pH indicator. Gelatin. Chitosan

Introduction:

Nowadays, the major challenge in food industries is to detect food spoilage in a very simple, low budget and a nondestructive way (Moradi et al., 2023). For this purpose, different biodegradable and multifunctional packaging films based on polysaccharides have attracted the consumer's interest. Modified systems known as 'intelligent materials' possess the ability to alter color in response to environmental changes (Kalpana et al., 2019; Capello et al., 2021). These materials can determine the status of food safety and can detect the changes in temperature pH and the freshness of packaged food during storage and transportation process (Merz et al., 2020; Valencia et al., 2019). The most significant and vital class of phenolic compounds in nature are called anthocyanins, and they are water-soluble pigments (Liu et al., 2020). Anthocyanins display exceptional colorings depending on many elements consisting of pH, chemical shape, oxygen, storage temperature, solvents and the presence of enzymes, proteins and metal ions (Bilgiç et al., 2019). Because of their ability to alter color and shape based on pH, anthocyanins are good choice for raw materials when making pH indicators (Whang et al., 2023).

Anthocyanins are the primary phenolic compounds in eggplant peels consisting of effective antioxidant activity. The peel has a very high anthocyanin content (Mauro et al., 2020). Eggplant has excessive antioxidant capacity because of phenolic compounds, with 30-60% focused in by-products, particularly the peel (Karimi et al., 2021).

Purple cabbage, or *Brassica oleracea* L., is a rich source of natural anthocyanins, water-soluble pigments acting as pH indicators. Extracted from the purple cabbage, these anthocyanins display various hues (red to blue) under different pH conditions, making them useful for assessing food quality by monitoring pH changes (Vo et al., 2019; Drozdowska et al., 2020). The anthocyanins derived from red/purple cabbage exhibit superior potential for intelligent packaging, owing to their enhanced stability during storage period and increased color variance across pH levels.

Blackcurrant (*Ribes nigrum*), also known as cassis, has its natural origin in central–northern Europe. It is cultivated as a branched shrub with a dark purple color peel. 90% of the total anthocyanin content in various cultivars of blackcurrants is made up of four primary anthocyanins: cyaniding-3-O-glucoside, cyaniding-3-O-rutinoside, delphinidin-3-O-glucoside, and delphinidin-3-O-rutinoside (Kurek et al., 2021; Mattila et al., 2016; Paunović et al., 2017). Over 70% of the antioxidant power in blackcurrants comes from these compounds called anthocyanins (Nour et al., 2013).

Chitosan is naturally occurring edible polymer (Muñoz et al., 2018; Singh et al., 2021). It is a linear macromolecular polysaccharide that has demonstrated its advantage due to its film forming ability in food packaging, low toxicity, biocompatibility, biodegradability, and renewability (Periera et al., 2015; Vo et al., 2019; Sun et al., 2020). Regardless of its benefits, chitosan has weak mechanical resistance and is frequently combined with other polymers to increase its mechanical properties (Periera et al., 2015; Vo et al., 2019). One method is to combine chitosan with other biopolymers such as gelatin, polyvinyl alcohol (PVA), and starch to enhance its barrier and mechanical properties (Koosha and Hamed, 2019; Sun et al., 2020; Liu et al., 2021). The ability of chitosan to solubilize in acetic acid and hydrochloric acid, contributes its film forming ability.

The combination of chitosan and a glycerol as plasticizer results in a composite film that is more elastic, robust, heat-stable and resistant to water penetration. Gelatin is used as a protein source to improve chitosan-based film's mechanical and barrier properties against water vapor and light. Moreover, in chitosan solution, Tween 20 is added as an emulsifier to improve the properties of film.

Objectives

- Development and characterization of intelligent packaging films from different organic sources.
- Application of developed intelligent films for shelf-life monitoring of fish.

Materials and Methods

Procurement of raw material

Analytical grade tween-20, glacial acetic acid, glycerol and chitosan were procured from Sigma Aldrich St. Louis Missouri USA and Merck Germany. Gelatin, eggplant peel, purple cabbage and black currant were procured from local market of Karachi.

Extraction of anthocyanin

Anthocyanins were extracted according to the method described by Pereira et al. 2015. A sample of 30-150 g of red cabbage/black currant/eggplant peel was chopped and impregnate with 80 mL ethanol-water (7:3) solution. The sample's pH was set to 2.0 using HCl (1 mol/L). The solution was kept at 4 °C for 24 hr. After filtering the mixture, the resulting extract was then

centrifuged for 10 minutes at 2000 rpm. Filter paper was used to filter the supernatant, and NaOH was used to neutralize the extract (2.5mol/L) to bring its pH down to 7.

Preparation of intelligent packaging film

Chitosan based intelligent packaging films were prepared via casting technique. For the preparation of CS based film forming solution, 1 g of chitosan and 2 g of gelatin were dissolved in 100 ml water and acetic acid (1% v/v) with continuous stirring. Glycerol (1% v/v) as a plasticizer and Tween-20 (1% v/v) as an emulsifier were added for the development of mechanical properties. Anthocyanin extract as a color indicator was added in the film solution. The film solution was then poured in petri plates and dried in hot air oven at 45 °C for 24 hr.

Characterization of developed films

Optical properties

The optical properties of the films, such as opacity and transparency, were determined using UV-Vis spectrophotometer. In a cuvette cell, film sample (4 x 1 cm) was inserted and at wavelength of 600 nm, the result was recorded. The transmittance of each sample was recorded thrice.

Moisture barrier property

The moisture barrier properties of the films were evaluated by measuring the water vapor permeability of the film samples by using method described by ASTM, which was also used by Brzoska et al. (2018). Films were placed to Payne permeability cups with 10 mL of distilled water and maintained at 25°C and 65% relative humidity. Weight changes were recorded every 1 h for a duration of 10 h.

Film thickness

Digital micrometer with an accuracy of 0.001 mm was used to evaluate the thickness of film. The film's thickness was determined by measuring the film from five different locations (Chen et al., 2021).

Porosity

Insoluble solvent approach was used as described by Liang et al. (2016) to determine the porosity of the film. Porosity was evaluated by saturating the film with chloroform. The film's weight was observed both before and after the immersion.

Viscosity

A rheometer was used to measure the viscosity of each film sample using a method described by (Sharifmehr et al., 2019). The concentric cylinder probe was filled with the 30 ml film forming solution. The temperature of the rheometer and the film solution was also monitored while checking the viscosity of the films.

Fish freshness monitoring

Fish fillets were utilized to test the effectiveness of anthocyanin extract-based films in fish freshness monitoring. A 30g of fish sample were placed into each petri dish. Film strips (2 in x 2 in) were affixed to the headspace of each dish. For seven days, all samples were kept at room temperature and the pH was recorded every 24 h.

Statistical analysis

The data was arranged in triplicate for each treatment, and it was shown as the mean \pm standard deviation of each treatment. To distinguish between the degrees of significance among treatments, statistical software (Statistix-8.1) was used for one-way analysis of variance (ANOVA) for the statistical analysis. The mean values for transparency, moisture barrier property, thickness, porosity, viscosity, and fish freshness monitoring were analyzed using Tuckey's test was conducted with a significance level ($p \leq 0.05$).

Results and Discussion

Transparency

Table 1 shows non-significant effect among different treatments. Not all formulations produced good transparency, as all film samples showed average clearance. The results were similar to the research of (Bilgiç et al., 2019) on chitosan and starch based eggplant peel anthocyanin extract-based film. The concentration of the chemicals and extracts used to make the film has a direct impact on transparency since certain compounds are opaque and some have thick colors that reduce film transparency. A highly significant effect was found for opacity. The highest value for transparency was obtained for 2% CGA-EPP which was 98.40 ± 3.30 %. The overall range was 89.87 ± 3.36 % to 98.40 ± 3.30 %. The highest value obtained for opacity was for 6 % black currant anthocyanin extract film 10.13 ± 0.01 %. The overall range was from 1.60 ± 0.01 % to 10.13 ± 0.01 %. According to research transparency should be above 75% which means our values are according to accepted range. Factors that affect transparency are plasticizers, stabilizer and particle size.

Tongnuanchan et al. (2013) believe that the reason chitosan and starch film samples, including extracts, frequently showed lower transmittance and increased opacity values could be due to the impermeable matrix light scattering across the film. Additionally, connected to anthocyanin capacity to absorb UV light are lower transmittance and greater opacity values (Peralta et al., 2019). This means that our data is similar to researches as we also got non-significant data for transparency and highly significant data for opacity and opacity increase as anthocyanin concentration increases. Similarly, Slavutsky et al. (2012) discovered that the inclusion of Nano-clay decreased transparency, depending on the dispersion technique used.

Thickness

Table 1 display the thickness of anthocyanin containing films and notable differences across treatments. As the concentration of anthocyanin in the chitosan gelatin-based intelligent film increased, so did its thickness. This shows an increasing trend with respect to anthocyanin concentration. The thickness of the film is important because it determines moisture and mechanical barrier characteristics of the film, and a thin film cannot operate as a proper barrier against moisture and gas penetration. Thickness is also a characteristic parameter to evaluate tensile strength and light barrier properties of film. Table 1 shows highly significant data with range from 0.16 ± 0.04 mm to 0.41 ± 0.02 mm. The highest values of thickness are shown for T₄, T₅ and T₆ which are chitosan gelatin-based films with EPP anthocyanin extracts as the content of anthocyanin compounds is higher in EPP as compared to the other two sources. The highest thickness specifically is observed in the film based on 6% EPP anthocyanin extract. Thicker films were produced according to Adilah et al. (2018), as the concentration of mango leaf extract increases because it changes the polymeric chain's structure and increases the distribution of phytochemicals in the film. The addition of anthocyanin extract increased the film's thickness in comparison to the control film, as reported by Merz et al. (2020). This suggests that anthocyanin affects the density of the film because of its electrostatic repulsion with macromolecules. According to Peralta et al. (2019) and Nogueira et al. (2019) similar outcomes were seen for films based on starch, chitosan and gelatin, all of which included anthocyanin from blackberry. In addition to the anthocyanin concentration, the plasticizer and emulsifier utilized also affect the thickness of the films because they provide the film a flexible and smooth structure.

Porosity

A highly significant data was obtained for porosity among different treatment shown in Table 1. An increasing trend was observed in porosity values with respect to concentration. It was observed that as the anthocyanin concentration increases from 2-6%, the porosity value also increases. The migration of active components is influenced by the porosity and integrity of the film, which in turn affects the mechanical strength of the intelligent packaging film. The highest

porosity was for T₃ 6% PC anthocyanin extract film which was 0.40±0.04 %. The overall range was from 0.19±0.04 % to 0.40±0.04 %. It was observed that T₁ - T₃ has higher porosity values which were films made by PC anthocyanin extracts. Similar values were found in the findings of Singh et al. (2021) in which values obtained were between 0.12–0.34% in which control film without extract have lower porosity as compared to the film with anthocyanin extracts. Higher porosity values are reported to affects the elongation at break, water absorption, and WVP.

Viscosity

Table 1 showed highly significant data. The viscosity of the emulsion increased significantly as the anthocyanin concentration increases from 2% to 4% to 6%. Higher viscosity is beneficial to obtain right thickness of film. Low viscous emulsion film led to improper thickness as the moisture is evaporated very quickly during drying. The variation in viscosity is due to factors such as molecular weight, particle size of emulsion, temperature and other processing conditions. The minimum viscosity value obtained is 0.15±0.01 poise that is of 2% PC anthocyanin extract-based film and highest value obtained is for 6% EPP anthocyanin extract-based film that is 0.53±0.02 poise. The average viscosity range is from 0.15±0.01 to 0.26±0.03 poise. The increasing trend of viscosity of emulsion with respect to concentration is similar to findings of Akhter et al. (2022) in which the viscosity of the wrapping solutions dramatically improved as the bees wax concentration was increased in the solution. Out of the three different extracts EPP anthocyanin extract-based films showed the highest viscosity which may be due to higher anthocyanin content in eggplant peel according to Clifford, (2000) which would increase the molecular weight and ultimately the viscosity, as compared to purple cabbage and black currant.

Table 1. Mean values for Transparency, Thickness, Porosity and Viscosity of Intelligent Packaging films

Treatments	Transparency	Thickness	Porosity	Viscosity
T ₁	97.50±3.26 ^a	0.19±0.01 ^f	0.21±0.01 ^e	0.15±0.01 ^f
T ₂	96.30±3.28 ^a	0.24±0.02 ^e	0.39±0.03 ^{ab}	0.19±0.02 ^e
T ₃	92.25±3.29 ^a	0.31±0.02 ^c	0.40±0.04 ^a	0.21±0.02 ^e
T ₄	98.40±3.30 ^a	0.31±0.04 ^c	0.19±0.04 ^e	0.34±0.01 ^c
T ₅	97.20±3.33 ^a	0.37±0.06 ^b	0.29±0.06 ^d	0.42±0.03 ^b
T ₆	95.50±3.28 ^a	0.42±0.02 ^b	0.29±0.06 ^d	0.53±0.02 ^a
T ₇	94.50±3.28 ^a	0.47±0.02 ^b	0.29±0.06 ^d	0.16±0.01 ^f
T ₈	93.50±3.28 ^a	0.52±0.02 ^b	0.29±0.06 ^d	0.19±0.04 ^e
T ₉	92.50±3.28 ^a	0.57±0.02 ^b	0.29±0.06 ^d	0.26±0.03 ^d

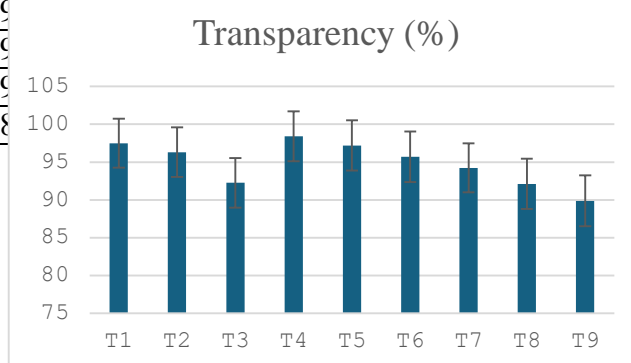
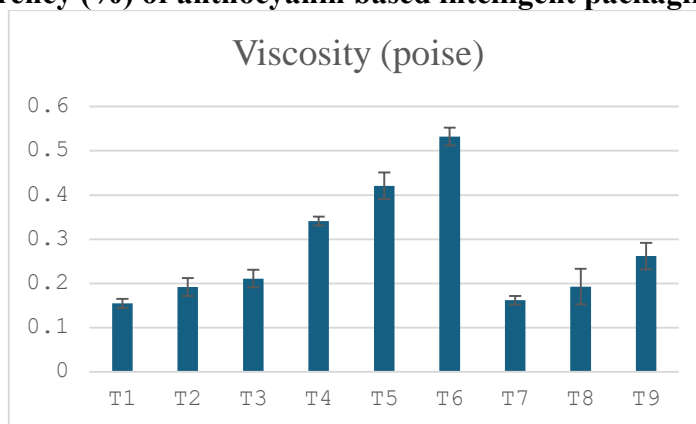


Figure 1. Transparency (%) of anthocyanin based intelligent packaging film**Figure 2. Viscosity (poise) of intelligent packaging films**

pH

Table 2 shows the results of purple cabbage (PC), eggplant peel (EPP) and black currant (BC) anthocyanin extract-based films of 2%, 4% and 6% respectively to monitor the freshness changes in fish. It was observed that highly significant data was obtained with respect to days, treatment and days*treatments. As the pH changes fish freshness/spoilage observed through color change. The color changes we observed were pale yellow to pink to dark green spots with respect to pH which changes from neutral to acidic and then to slightly basic. The highest pH with respect to days was found on the 7th day which is 7.73 ± 0.08 . With respect to treatment the highest pH obtained was for 4% EPP anthocyanin extract-based film. Majority of the color green color changes were obtained at slightly basic pH and the yellow, orange and pinkish color change was observed at acidic pH mostly. The most noticeable color change was observed in EPP anthocyanin extract-based film. According to Li et al. (2021), the chitosan-based purple tomato anthocyanin extract-based intelligent film, changed color in response to pH as follows: pink (pH = 3) → light purple (pH = 5) → bright green (pH = 7) → light greenish (pH = 9) → light yellow (pH = 11). The CS/30% PTA film shifted color from fuchsia (pH = 3) to deep purple (pH = 5), dark blue (pH = 7), green (pH = 9), and finally yellow-green (pH = 11). The CS/50% PTA film shifted color from fuchsia (pH = 3) to blue (pH = 11) to green. The one with the most obvious and discernible color change at various pH levels was the CS/10% PTA film.

Table 2. Mean values of pH for treatment

Treatments	Means
T ₁	5.98 ± 0.01^d
T ₂	5.75 ± 0.03^c
T ₃	6.61 ± 0.04^c
T ₄	7.26 ± 0.09^b
T ₅	7.75 ± 0.01^a
T ₆	7.31 ± 0.02^b
T ₇	5.96 ± 0.04^{de}
T ₈	6.05 ± 0.02^d
T ₉	6.58 ± 0.08^c

Table 3. Mean vales of pH for days

Days	Means
1	7.40 ± 0.01^b
2	6.35 ± 0.02^c

3	6.15±0.03 ^d
4	6.40±0.09 ^c
5	5.67±0.01 ^e
6	6.40±0.03 ^c
7	7.73±0.08 ^a

Mean carrying same letters are not significantly different. Column values sharing similar alphabetical letters are statistically alike.

Table 4. Mean values of pH for Treatment*Days

Treatments	Days	Means
T ₁	1	7.60±0.01 ^{f-k}
T ₁	2	6.65±0.02 ^{l-q}
T ₁	3	5.70±0.04 ^{s-v}
T ₁	4	5.35±0.06 ^{u-x}
T ₁	5	5.00±0.09 ^{v-y}
T ₁	6	4.70±0.09 ^{xyz}
T ₁	7	6.91±0.01 ^{k-p}
T ₂	1	7.60±0.03 ^{f-k}
T ₂	2	6.450±0.04 ^{n-r}
T ₂	3	5.30±0.01 ^{u-x}
T ₂	4	5.05±0.01 ^{v-y}
T ₂	5	4.80±0.02 ^{xyz}
T ₂	6	4.20±0.02 ^z
T ₂	7	6.90±0.01 ^{k-p}
T ₃	1	7.60±0.05 ^{f-k}
T ₃	2	7.00±0.05 ^{j-o}
T ₃	3	6.40±0.03 ^{n-s}
T ₃	4	6.20±0.01 ^{p-t}
T ₃	5	6.00±0.04 ^{q-u}
T ₃	6	5.60±0.03 ^{t-w}
T ₃	7	7.50±0.02 ^{f-k}
T ₄	1	7.00±0.04 ^{j-o}
T ₄	2	5.00±0.01 ^{v-y}
T ₄	3	6.70±0.05 ^{l-q}
T ₄	4	8.40±0.05 ^{a-e}
T ₄	5	8.16±0.04 ^{b-f}
T ₄	6	7.92±0.06 ^{c-h}
T ₄	7	7.69±0.04 ^{e-j}
T ₅	1	7.00±0.06 ^{j-o}
T ₅	2	6.10±0.06 ^{q-t}
T ₅	3	7.34±0.04 ^{g-l}
T ₅	4	8.59±0.06 ^{abc}
T ₅	5	8.03±0.07 ^{b-g}
T ₅	6	8.52±0.08 ^{a-d}
T ₅	7	8.73±0.08 ^{ab}
T ₆	1	7.00±0.04 ^{j-o}
T ₆	2	6.30±0.04 ^{o-t}
T ₆	3	7.45±0.06 ^{f-k}
T ₆	4	8.60±0.05 ^{abc}

T ₆	5	4.50±0.02 ^{yz}
T ₆	6	8.46±0.06 ^{a-d}
T ₆	7	8.90±0.06 ^a
T ₇	1	7.60±0.04 ^{f-k}
T ₇	2	6.20±0.04 ^{p-t}
T ₇	3	4.80±0.02 ^{xyz}
T ₇	4	4.65±0.03 ^{xyz}
T ₇	5	4.80±0.03 ^{xyz}
T ₇	6	5.73±0.04 ^{r-v}
T ₇	7	7.97±0.06 ^{c-h}
T ₈	1	7.60±0.06 ^{f-k}
T ₈	2	6.35±0.04 ^{o-s}
T ₈	3	5.10±0.03 ^{v-y}
T ₈	4	4.95±0.02 ^{wxy}
T ₈	5	5.10±0.03 ^{v-y}
T ₈	6	6.03±0.04 ^{q-u}
T ₈	7	7.26±0.06 ^{h-m}
T ₉	1	7.60±0.06 ^{f-k}
T ₉	2	7.10±0.05 ⁱ⁻ⁿ
T ₉	3	6.60±0.04 ^{m-q}
T ₉	4	5.85±0.02 ^{r-u}
T ₉	5	4.70±0.02 ^{xyz}
T ₉	6	6.44±0.03 ^{n-r}
T ₉	7	7.79±0.06 ^{d-i}



Figure 3. Showing the color variation of films in response to varying pH

Moisture Barrier Property

WVP is the film's ability to allow water vapor to pass through it. Maintaining adequate WVP in intelligent packaging film is essential for protecting product quality, increasing shelf life, and guaranteeing customer's pleasure. Therefore, while designing and developing intelligent packaging solutions, careful consideration of material selection, structure, and environmental aspects is necessary. Table 5 shows highly significant data for WVP with respect to different treatment. A decreasing trend is seen in the WVP with respect to concentration. As the concentration increased from 2% -6% the WVP decreased from $4.32 \pm 0.01 \text{ g/m}^2$ to $3.28 \pm 0.02 \text{ g/m}^2$ for purple cabbage anthocyanin-based films, $6.38 \pm 0.09 \text{ g/m}^2$ to $2.67 \pm 0.01 \text{ g/m}^2$ for EPP anthocyanin-based film and $6.69 \pm 0.09 \text{ g/m}^2$ to $2.03 \pm 0.08 \text{ g/m}^2$ for BC anthocyanin-based films. The values range from $2.03 \pm 0.08 \text{ g/m}^2$ to $6.69 \pm 0.09 \text{ g/m}^2$ in which the highest value is for 2% BC anthocyanin extract film. The reason behind is that the hydroxyl (-OH) groups present in anthocyanin have the ability to create hydrogen bonds with water molecules and these bonds limit the flow of water through the packing material. Also, anthocyanin physically takes up space in the film matrix, erecting obstacles that impede the flow of water molecules and hence decreasing the permeability of water vapors. Similar results were reported by Alnadari et al. (2023) who revealed that the WVP of the films reduced from 3.86×10^{-11} to $1.17 \times 10^{-11} \text{ g} \cdot \text{m}^{-1} \text{ s}^{-1} \text{ Pa}^{-1}$, when the content of anthocyanin increased from 1-1.5%. This shows that anthocyanin may enhance the water barrier qualities of the films. According to Bilgiç et al. (2019) the increase in barrier ability against water in chitosan-based film was observed when eggplant peel anthocyanin extracts were added. A similar trend was observed by Kurek et al. (2018) for chitosan films including blackberry and blueberry extracts.

Table 5. Mean values for moisture barrier property

Treatments	Means
T ₁	4.32 ± 0.01^d
T ₂	3.72 ± 0.02^f
T ₃	3.28 ± 0.02^g
T ₄	6.38 ± 0.09^b
T ₅	5.73 ± 0.04^c
T ₆	2.67 ± 0.01^h
T ₇	6.69 ± 0.09^a
T ₈	3.84 ± 0.08^e
T ₉	2.03 ± 0.08^i

Conclusion

The film's mechanical characteristics, barrier qualities, and general performance are all impacted by its thickness. Therefore, knowing the thickness makes it easier to modify and understand the film's properties, such flexibility and protection, for certain uses. The test results show the thickness increased significantly as the anthocyanin concentration increases. The highest thickness is observed in the 6% CGA-EPP film as EPP contain high amount of anthocyanin as compared to other sources. Viscosity affects the homogeneity and film forming process and maintaining viscosity control helps achieve consistent to performance throughout manufacture and application and guarantees consistency in the film's qualities. The test results show increasing trend as the anthocyanin concentration increases. The viscosity of the film ranges from 0.15 ± 0.01 poise to 0.26 ± 0.03 poise. By examining transparency, one may make sure that the film stays clear and improve the attractiveness and visibility of the goods also is will significantly show color changes. The test results show that the transparency of the films is in accepted range i.e., above 75%. Maintaining the quality and freshness of the packed food requires an understanding of the film's water vapor permeability. Low water vapor permeability

films aid in maintaining the product's moisture content and guard against dehydration or spoiling. The test results show decreasing trend with respect to concentration. The overall values range from $2.03 \pm 0.08 \text{ g/m}^2$ to $6.69 \pm 0.09 \text{ g/m}^2$. The highest WVP obtained was for 6% CGA-BC film. The natural pH indicators in the films called anthocyanin react to changes in pH by changing color. Testing the film's color at different pH levels is a vital step in determining how well the film functions as a freshness indication. The highest pH with respect to days was found on the 7th day which is 7.73 ± 0.08 . The highest pH obtain was for 4% CGA-EPP film. At basic pH values the color change obtained was green and at acidic pH values the color change was yellow, orange and pink. Porosity affects the film's gas and moisture barrier properties. Analyzing porosity helps in understanding the film's ability to regulate gas exchange, such as oxygen and carbon dioxide, which is important for increasing the shelf life of the packaged food products. The test results show increasing trend in porosity with respect to concentration. The highest values of porosity obtained was for CGA-PC films with overall range from $0.19 \pm 0.04 \%$ to $0.40 \pm 0.04 \%$.

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