

Effect of Citric Acid Concentration on the Properties of PVA/Bitter Gourd Composite Films for Potential Wound Dressing Applications

Nurain Faqihah Badrul Hisham¹, Sarina Mohamad², Nurul Aizan Mohd Zaini³,
Nor Hafizah Che Ismail⁴, Siti Nor Din⁵, Faiezah Hashim^{6*}

^{1,2,3,4,5,6}Faculty of Applied Sciences, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600 Arau, Perlis, Malaysia

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ABSTRACT

Polymer-based films with suitable mechanical, thermal, and antibacterial characteristics are increasingly being explored for potential wound-dressing applications. This study investigated the effect of different citric acid (CA) concentrations (0, 1, 2.5, and 5 wt.%) on the structural, mechanical, thermal, and antibacterial properties of polyvinyl alcohol (PVA)/bitter gourd (BG) composite films. The films were prepared using the solution casting method. Fourier Transform Infrared (FTIR) spectroscopy showed slight changes in the O–H, C=O, and C–O absorption bands following CA incorporation, suggesting changes in intermolecular interactions within the PVA/BG matrix. The control film showed the highest tensile strength (8.47 ± 1.42 MPa), Young's modulus (53.17 ± 6.96 MPa), and elongation at break ($166.61 \pm 51.43\%$). Among the films containing CA, the 2.5 wt.% CA formulation showed a better balance of tensile strength and Young's modulus. Differential scanning calorimetry (DSC) showed changes in the melting and crystallization behaviour with increasing CA concentration, indicating that CA influenced the molecular arrangement within the PVA/BG matrix. Antibacterial evaluation of the film-forming solutions showed increasing inhibition against *Bacillus subtilis* with increasing CA concentration, with the 5 wt.% CA formulation producing the largest inhibition zone (10.67 ± 0.58 mm), whereas the differences against *Escherichia coli* were not statistically significant. Overall, the findings demonstrate that

^{6*}Corresponding author. E-mail address

: faiezahhashim@uitm.edu.my

CA concentration influenced the properties of the PVA/BG formulations and provide useful information for their further development as potential wound-dressing materials. Further evaluation of the final films, particularly their antibacterial performance and other wound-dressing-related properties, is required to establish their suitability for practical applications.

1. INTRODUCTION

The growing interest in sustainable and biocompatible materials has encouraged the development of polymer-based materials for biomedical applications, particularly wound dressing materials. Polyvinyl alcohol (PVA) is a water-soluble synthetic polymer commonly used in biomedical applications due to its biocompatibility, biodegradability, film-forming ability, and non-toxic nature [1]. The abundant hydroxyl groups present in PVA facilitate hydrogen bonding and interactions with other functional materials, making it a suitable matrix for hydrogel and wound dressing applications [2]. However, its sensitivity to water and limited structural stability may affect its performance under moist environments.

Several approaches have been explored to modify the properties of PVA-based materials, including the use of crosslinking agents. Citric acid (CA), a naturally occurring tricarboxylic acid, is particularly attractive because it can act as an environmentally friendly modifier and potential crosslinking agent [3]. The carboxyl groups of CA can interact with the hydroxyl groups of PVA through hydrogen bonding and, under suitable conditions, may also participate in esterification reactions. These interactions can influence the arrangement of the polymer chains and consequently alter the properties of the resulting films. Previous studies have reported that incorporation of CA can alter the physicochemical, mechanical, and water-related properties of PVA-based systems [4].

Besides, incorporation of natural bioactive materials also offers another approach to develop functional polymer films. Bitter melon (*Momordica charantia* L.) is a medicinal plant rich in phenolic compounds, flavonoids, and glycosides, which exhibit antioxidant, antimicrobial, and anti-inflammatory activities. Previous studies have also reported that bitter melon extracts can promote wound healing by accelerating tissue regeneration, enhancing collagen formation, and reducing microbial infections [5]. When introduced into PVA, these bioactive compounds may interact with PVA through hydrogen bonding. These characteristics make bitter melon an interesting component for the development of polymer-based materials intended for biomedical applications [6].

Although PVA/CA systems and PVA materials containing bitter melon have been investigated separately, limited information is available on the influence of different CA concentrations on PVA films containing bitter melon powder. In particular, the combined effects of CA incorporation on the molecular interactions, thermal behaviour, tensile properties, and antibacterial activity of PVA/BG films remain insufficiently understood. Therefore, this study investigates PVA/BG films containing different CA concentrations (0, 1, 2.5, and 5 wt.%) to determine how CA incorporation influences their structural, thermal, mechanical, and antibacterial characteristics. The findings are intended to provide preliminary

information on the potential of PVA/BG composite films for further development toward wound dressing applications.

2. EXPERIMENTAL METHODOLOGY

2.1 Materials

Polyvinyl alcohol (PVA) (R&M Chemicals, Essex, United Kingdom), with a degree of hydrolysis of 86.0–89.0 mol% and a viscosity of 21.0–26.0 cP according to the manufacturer's specification, was used as the polymer matrix. Fresh bitter melon (*Momordica charantia* L.) fruits were purchased from a local market in Perlis and used as the source of natural antibacterial filler. Citric acid (CA) (ChemPur Pvt.) and glycerol ($\geq 99.0\%$, Sigma-Aldrich, Merck) was used as a plasticizer to improve the flexibility of the PVA films. Distilled water was used as the solvent throughout the study. Unless otherwise stated, all chemicals used were of analytical grade and used without further purification.

2.2 Preparation of Bitter Melon Filler

Fresh bitter melon (*Momordica charantia* L.) fruits were rinsed thoroughly with distilled water to remove any surface impurities. After removing the seeds and inner pith, the flesh and peel were cut into thin slices and dried in an oven at 60 °C for 24–48 h until a constant weight was obtained. The dried BG was then ground using a high-speed grinder to obtain a fine powder. The BG powder was passed through a 16-mesh sieve with an aperture size of 1.19 mm to obtain a powder with a maximum particle size of approximately 1.19 mm. The sieved BG powder was stored in an airtight container until further use. The BG loading was fixed at 5 wt.% based on the weight of PVA for all film formulations.

2.3 Preparation of PVA/Bitter Melon Films

The PVA/BG films were prepared by solution casting method. PVA (5 g) was added to distilled water (50 mL) and stirred continuously at 90 °C for 30–45 min until completely dissolved. Then, BG powder (0.25g, 5 wt.% based on PVA), was added, and the mixture was stirred at 60–70 °C for 20 min to obtain a well dispersed mixture. Next, glycerol (1g, 20 wt.% of PVA) was added, followed by stirring for another 10 min. CA was then incorporated at 0, 1, 2.5, and 5 wt% based on the weight of PVA, and mixing was continued for 10–15 min until a homogeneous mixture was obtained. The resulting film solutions were poured into Petri dishes and dried at room temperature for 24 h, followed by oven drying at 50 °C for 3–4 h. The dried films were removed from Petri dishes and conditioned at 25 °C and 50% relative humidity for 48 h before testing.

2.4 Characterisation and Testing

2.4.1 Fourier Transform Infrared (FTIR) Analysis

The FTIR (Thermo Fisher Scientific Nicolet iS 10) equipped with Attenuated Total Reflectance (ATR) was used to obtain the spectra of the sample at room temperature. FTIR analysis was carried out to identify the functional groups and evaluate the possible molecular interactions between PVA, BG powder, and CA. The analysis was performed in the range of 4000–500 cm^{-1} with 16 scans and a resolution of 4 cm^{-1} .

2.4.2 Differential Scanning Calorimetry (DSC) Analysis

Thermal properties of the films were analysed using Jade Differential Scanning Calorimetry (DSC) (Perkin Elmer, USA). Approximately 10-15 mg samples were sealed in aluminium pan and analysed under nitrogen atmosphere. The heating rate was set at 20 °C/min under nitrogen flow of 20 mL/min. The samples were first heated from 30 to 200 °C at a heating rate of 20 °C/min, followed by cooling from 200 to 30 °C. The melting temperature (T_m), crystallization temperature (T_c), crystallization and melting enthalpy were assessed from the DSC thermogram.

2.4.3 Tensile Test

The tensile properties of the films were evaluated using a universal testing machine (Instron Model 5569, Instron Corporation, Norwood, MA, USA) according to ASTM D882. The film specimens were cut into rectangular strips measuring 70 mm × 10 mm and tested at a crosshead speed of 10 mm/min. The thickness of each specimen was measured prior to tensile testing. The average film thicknesses were 0.620 ± 0.000 , 0.828 ± 0.031 , 0.770 ± 0.028 , and 0.860 ± 0.042 mm for PVA/BG, PVA/BG/CA1, PVA/BG/CA2.5, and PVA/BG/CA5, respectively. Tensile strength, Young's modulus, and elongation at break were determined from the resulting stress-strain data.

2.4.4 Antibacterial Activity by Disc Diffusion Assay

The antibacterial activity of the PVA/BG film-forming solutions containing different CA concentrations (1, 2.5, and 5 wt.%) was evaluated against *Escherichia coli* and *Bacillus subtilis* using the agar disc diffusion method. The solutions tested were corresponded to the respective PVA/BG formulations prior to casting and drying. Mueller–Hinton agar (MHA) and nutrient broth (NB) were prepared according to the manufacturer's instructions and sterilized by autoclaving at 121°C for 15 min. The bacterial inoculum was prepared in nutrient broth and incubated at 37 °C with shaking at 200 rpm until the culture reached the turbidity equivalent to the 0.5 McFarland standard (approximately 1.5×10^8 CFU/mL). The bacterial suspension was then spread evenly onto the surface of MHA plates using a sterile cotton swab. Sterile 6-mm paper discs were loaded with 20 µL of the respective film-forming solutions and placed onto the inoculated agar surface. Gentamicin (50 mg/mL) and a blank disc served as positive and negative controls, respectively. The plates were incubated at 37 °C for 24 h, and the diameter of the inhibition zone surrounding each disc was measured in millimetres. All experiments were performed in triplicate, and the results were reported as mean ± standard deviation.

2.5 Statistical Analysis

The antibacterial data was expressed as mean ± standard deviation (SD) from triplicate measurements. Differences among the formulations for each bacterial strain were analyzed using one-way analysis of variance (ANOVA) with statistical significance set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 FTIR Analysis

Fig. 1 and Table 1 present FTIR spectra and characteristic absorption bands of BG powder and PVA/BG films containing different CA concentrations. The spectra were examined to identify changes in the functional groups and possible interactions among PVA, glycerol, BG powder, and CA within the film matrix.

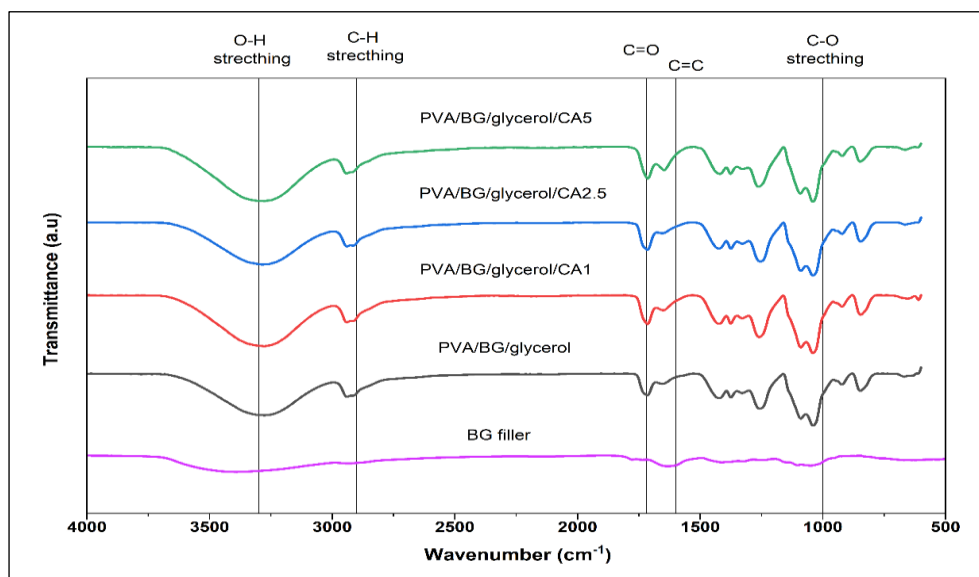


Fig. 1. FTIR spectra of PVA/bitter gourd films with various CA concentrations

Table 1. Values in FTIR spectra for PVA/bitter gourd films with various CA concentrations

Sample	O-H (3400-3200 cm ⁻¹)	C-H (3000-2840 cm ⁻¹)	C=O (1730-1715 cm ⁻¹)	C=C (1648-1658 cm ⁻¹)	C-O (1040-1100 cm ⁻¹)
BG Powder	3390	2930	1776	1629	1102
PVA/BG	3277	2939	1715	1653	1089
PVA/BG/CA1	3278	2940	1715	1649	1089
PVA/BG/CA2.5	3286	2940	1715	1647	1090
PVA/BG/CA5	3277	2941	1713	1647	1092

The FTIR spectrum of BG powder showed a broad O–H stretching band at 3390 cm⁻¹, which can be associated with the hydroxyl groups from phenolic compounds, flavonoids and saponins. The absorption bands at 2930, 1776, 1629 and 1102 cm⁻¹ were assigned to C–H stretching, carbonyl (C=O), aromatic C=C

and C–O stretching vibrations, respectively. These functional groups are consistent with the phytochemical components previously reported in BG [5,7].

After BG was incorporated into the PVA/glycerol matrix, the O–H stretching band shifted from 3390 to 3277 cm^{-1} . This shift may reflect changes in hydrogen-bonding interactions among PVA, glycerol, and BG constituents. The carbonyl-related band was observed at approximately 1715 cm^{-1} , while bands at 1653 and 1089 cm^{-1} , were associated with aromatic C=C and C–O vibrations, respectively. The presence of these characteristic bands suggests that BG was incorporated into the PVA matrix, with hydrogen bonding and physical interactions likely contributing to the interaction between the components [8].

The addition of CA resulted in relatively small changes in the FTIR spectra. The O–H band varied between 3277 and 3286 cm^{-1} , while the C=O band remained within 1713–1715 cm^{-1} . A small shift in the C–O band was also observed, from 1089 cm^{-1} for the control film to 1092 cm^{-1} for the film containing 5 wt.% CA. These changes suggest that CA influenced the interaction among the components within the PVA/BG/glycerol matrix.

Overall, the FTIR results suggest that CA influenced the molecular interactions within the PVA/BG films, particularly those involving hydroxyl, carbonyl, and C–O-containing groups. The observed spectral changes are consistent with changes in the hydrogen-bonding environment and possible interactions between CA and the hydroxyl-containing components. Although esterification may have occurred, the relatively small spectral changes do not provide conclusive evidence of covalent crosslinking. Therefore, the FTIR findings are mainly interpreted as changes in intermolecular interactions within the film matrix.

3.2 DSC Analysis

The thermal behaviour of the PVA/BG films containing different CA concentrations was evaluated using DSC. The melting temperature (T_m), melting enthalpy (ΔH_m), crystallization temperature (T_c), and crystallization enthalpy (ΔH_c) are summarized in Table 2.

Table 2. DSC parameters of PVA/BG film with different CA concentrations

Samples	Melting Temperature, T_m (°C)	ΔH_m (J/g)	Crystallization Temperature, T_c (°C)	ΔH_c (J/g)
PVA/BG	163.28	170.5066	125.30	24.5744
PVA/BG/CA1	157.64	223.1001	104.31	29.4095
PVA/BG/CA2.5	142.01	236.3024	100.57	23.3664
PVA/BG/CA5	146.49	237.1574	89.58	15.7640

The control PVA/BG film showed a T_m of 163.28 °C. With the addition of CA, T_m decreased to 157.64 °C at 1 wt.% CA and further to 142.01 °C at 2.5 wt.% CA, before increasing slightly to 146.49 °C at 5 wt.% CA. The overall reduction in T_m suggests that CA affected the arrangement and packing of PVA chains within the PVA/BG/glycerol matrix. The carboxyl groups of CA may interact with hydroxyl-

containing components in the film, modifying the existing hydrogen-bonding network and consequently affecting the arrangement of PVA chains. Similar changes in melting behaviour have been reported PVA-based systems following the addition of components that alter intermolecular interactions and chain packing [9]. In contrast to T_m , ΔH_m increased from 170.51 J/g for the control film to 223.10, 236.30, and 237.16 J/g for films containing 1, 2.5, and 5 wt.% CA, respectively. The increase in ΔH_m indicates that CA incorporation influenced the molecular organization of the film matrix, resulting in changes in the energy required to melt the polymer domains. This behaviour may arise from changes in intermolecular interactions and chain arrangement among PVA, BG, glycerol, and CA.

The T_c decreased progressively from 125.30 °C for the control film to 104.31, 100.57, and 89.58 °C as the CA concentration increased. This trend suggests that CA affected the ability of the PVA chains to arrange into an ordered structure during cooling, causing crystallization to occur at lower temperatures. A similar reduction in T_c has been reported in PVA-based systems when intermolecular interactions alter regular chain packing [10]. The ΔH_c initially increased from 24.57 J/g for the control film to 29.41 J/g at 1 wt.% CA, followed by decreases to 23.37 and 15.76 J/g at 2.5 and 5 wt.% CA, respectively. The lower ΔH_c at higher CA concentrations suggests that less heat was released during crystallization, which may be associated with a reduced extent of chain organization during cooling. Similar observations have been reported for highly crosslinked PVA composites [11,12].

Overall, the DSC results show that the addition of CA affected both the melting and crystallization behaviour of the PVA/BG films. The changes observed in T_m , T_c , ΔH_m , and ΔH_c suggest that CA influenced the arrangement and interactions of the polymer chains within the film matrix. This trend is also consistent with the FTIR findings, which showed changes in the intermolecular interactions following CA incorporation.

3.3 Tensile Properties

The Table 3 presents the tensile properties of the PVA/BG films prepared with different CA concentrations. The corresponding tensile strength, Young's modulus, and elongation at break are shown in Figs. 2-4. These results were used to examine the effect of CA concentration on the mechanical properties of the films.

Table 3. Tensile properties of PVA/BG films with different concentrations of CA

Samples	Tensile strength (MPa)	Young's Modulus (MPa)	Elongation at break(%)
PVA/BG	8.47 ± 0.98	53.17 ± 1.13	166.61 ± 10.86
PVA/BG/CA1	4.95 ± 0.83	29.35 ± 0.94	116.38 ± 12.14
PVA/BG/CA2.5	5.93 ± 0.96	36.86 ± 1.02	139.19 ± 12.34
PVA/BG/CA5	4.34 ± 0.43	14.60 ± 0.73	120.79 ± 10.06

Fig. 2 shows the tensile strength of the PVA/BG films at different CA concentrations. The control film exhibited the highest tensile strength of 8.47 MPa. Following the addition of 1 wt.% CA, the tensile strength decreased to 4.95 MPa. Increasing the CA concentration to 2.5 wt.% resulted in a moderate increase to 5.93 MPa, although this value remained below that of the control. At 5 wt.% CA, the tensile strength decreased further to 4.34 MPa. Therefore, CA incorporation did not improve the tensile strength relative to the control film; however, 2.5 wt.% CA gave the highest tensile strength among the CA-containing formulations. The reduction in tensile strength following CA addition may be related to changes in the intermolecular interactions within the PVA/BG/glycerol matrix. The presence of CA may modify the existing hydrogen-bonding interactions among the film components and consequently affect the arrangement of the polymer chains. The partial recovery in tensile strength at 2.5 wt.% CA suggests that this concentration provided a more favourable balance of interactions compared with the other CA-containing formulations. At 5 wt.% CA, the greater amount of CA may have further altered the interactions and arrangement of the film components, resulting in a lower resistance to tensile loading. Previous studies on PVA/starch/glycerol/CA films have similarly shown that tensile behaviour is strongly dependent on the relative composition of the film-forming system, indicating that the mechanical response arises from the combined interactions among the polymer, plasticizer, and CA rather than the concentration of a single component alone [13,14].

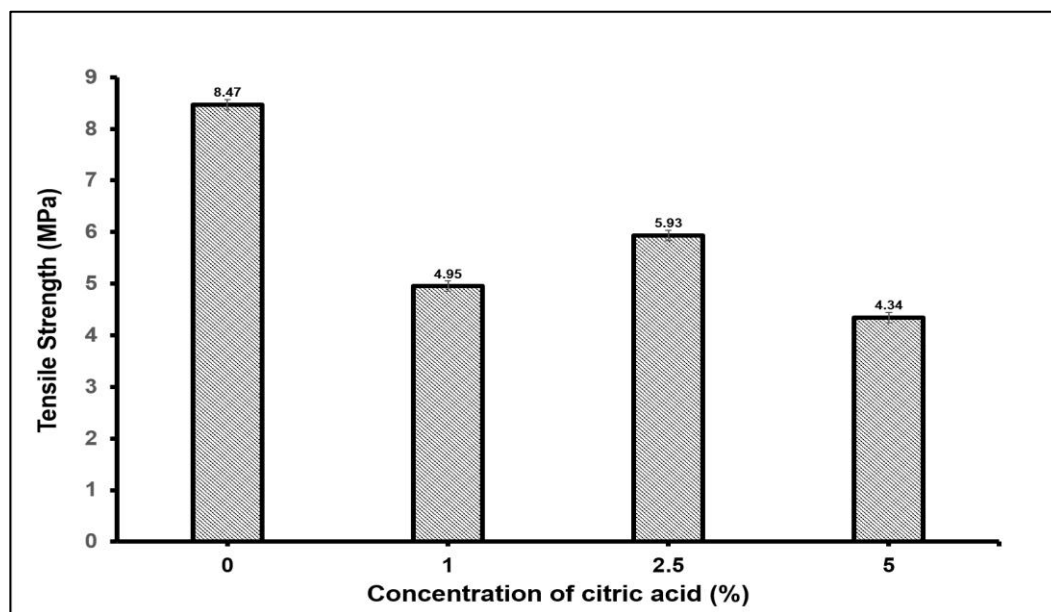


Fig. 2. Tensile strength of PVA/BG films with different concentrations of CA

Fig. 3 shows the Young's modulus of the PVA/BG films. The control film recorded the highest modulus of 53.17 MPa. With the addition of 1 wt.% CA, the modulus decreased to 25.79 ± 7.68 MPa, followed by an increase to 37.15 ± 3.13 MPa at 2.5 wt.% CA. At 5 wt.% CA, the modulus decreased further to 14.64 ± 0.73 MPa, the lowest value among the formulations. Although the 2.5 wt.% CA formulation showed a higher modulus than the other CA-containing films, it remained lower than the control. These results indicate that CA incorporation generally reduced the stiffness of the PVA/BG films under the processing conditions used in this study.

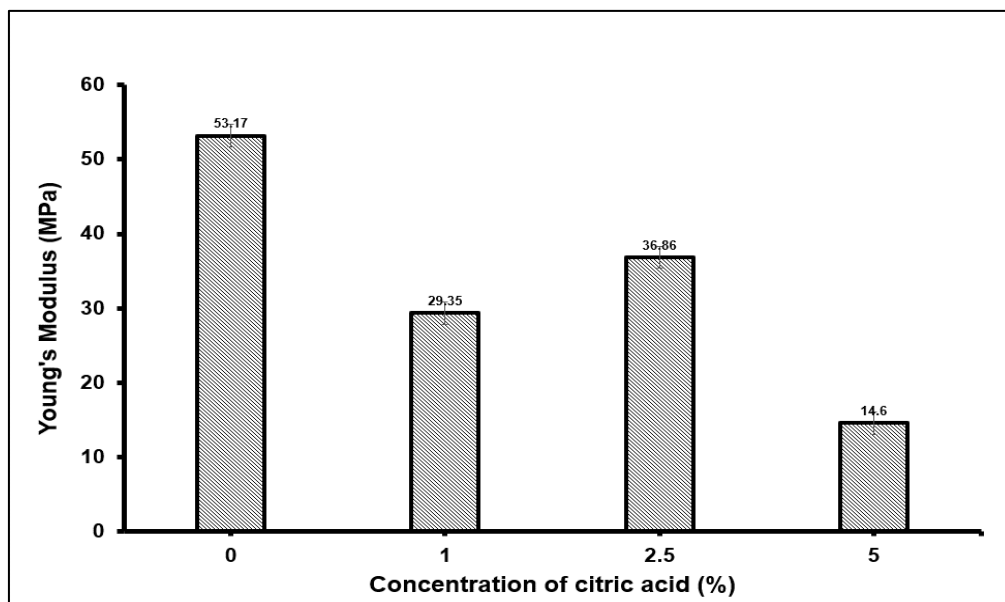


Fig. 3. Young Modulus of PVA/BG films with different concentrations of CA

The changes in Young's modulus may be associated with changes in intermolecular interactions and polymer-chain arrangement following CA incorporation. The higher modulus at 2.5 wt.% CA compared with 1 and 5 wt.% CA suggests that the interactions among PVA, BG, glycerol, and CA at this concentration provided comparatively greater resistance to deformation. In contrast, the marked reduction at 5 wt.% CA indicates that a higher CA content may have increasingly disturbed the interactions that contribute to the stiffness of the PVA/BG matrix. Similar behaviour has been reported in CA-crosslinked PVA systems, where excessive crosslinking adversely affected the mechanical performance of the polymer matrix [15].

Fig. 4 shows the elongation at break of the PVA/BG films. The control film exhibited the highest elongation at break of 166.61%, indicating greater flexibility compared with the CA-containing films. The addition of 1 wt.% CA reduced the elongation at break to 116.38%. At 2.5 wt.% CA, the value increased to 139.19%, followed by a decrease to 120.79% at 5 wt.% CA. Similar to the tensile strength and Young's modulus results, the 2.5 wt.% CA formulation showed the highest elongation among the CA-containing films, although its value remained below that of the control.

The lower elongation observed after CA incorporation suggests that the presence of CA changed the intermolecular interactions within the film matrix and affected the ability of the polymer chains to move during tensile deformation. The partial recovery in elongation at 2.5 wt.% CA may indicate a more favourable balance of molecular interactions, allowing greater chain movement than in the 1 and 5 wt.% CA formulations. Similar findings have been reported for CA-crosslinked PVA films, where high crosslink density reduced chain flexibility and ductility [16].

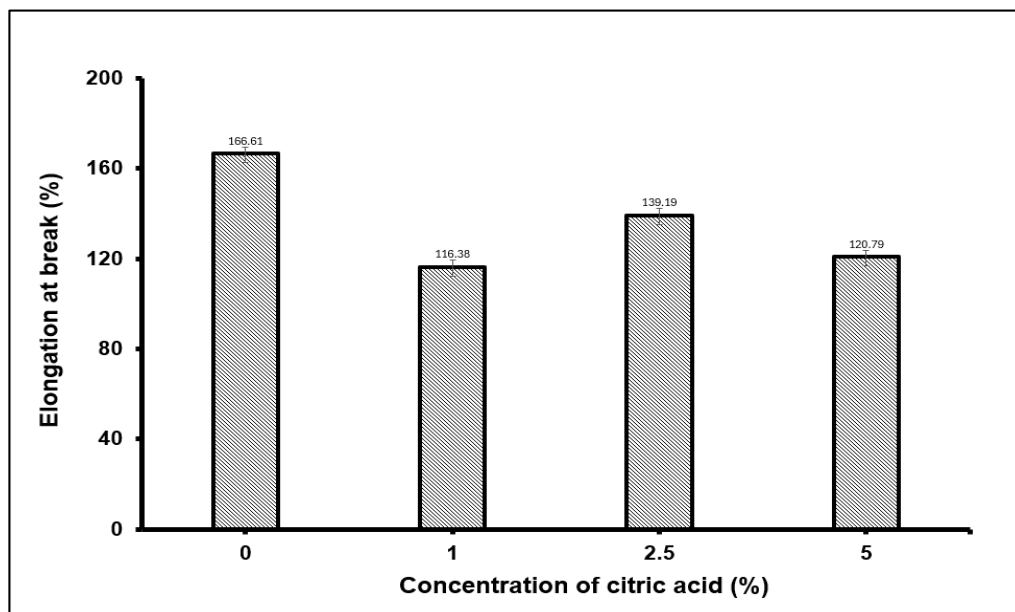


Fig. 4. Elongation at break of PVA/BG films with different concentrations of CA

Overall, the PVA/BG films showed the highest overall tensile properties, while the film containing 2.5 wt.% CA showed a better balance of tensile strength and Young's modulus among the modified formulations. These findings suggest that the mechanical behaviour of the films was influenced by the combined interactions among PVA, BG, glycerol, and CA.

3.4 Antibacterial Activity of PVA/Bitter Gourd Films

The antibacterial activity of the PVA/BG film-forming solutions containing different CA concentrations was evaluated against *Escherichia coli* and *Bacillus subtilis* using the disc diffusion assay. The inhibition-zone diameters are summarized in Table 4. Gentamicin, used as the positive control, produced the largest inhibition zones against both bacterial strains, confirming the validity of the disc diffusion assay. The control film exhibited relatively small inhibition zones of 7.00 ± 1.00 mm against *B. subtilis* and 6.33 ± 0.58 mm against *E. coli*, indicating limited antibacterial activity. The inhibition is mainly attributed to the bioactive compounds present in bitter gourd, which possess natural antimicrobial properties [17].

For *E. coli*, the inhibition-zone diameter increased slightly from 6.00 ± 0.00 mm for the control to 6.33 ± 0.58 , 7.00 ± 1.00 , and 7.67 ± 0.58 mm with the addition of 1, 2.5, and 5 wt.% CA, respectively. Although a gradual increase was observed with increasing CA concentration, one-way ANOVA showed that the differences among the formulations were not statistically significant ($p = 0.064$). Therefore, the results indicate only a limited inhibitory response against *E. coli* under the conditions used in this study. A more pronounced response was observed against *B. subtilis*. The inhibition-zone diameter increased from 6.00 ± 0.00 mm for the control to 7.67 ± 0.58 , 9.33 ± 0.58 , and 10.67 ± 0.58 mm for the formulations

containing 1, 2.5, and 5 wt.% CA, respectively. One-way ANOVA indicated a significant overall effect of CA concentration on the inhibition response ($p = 0.001$). The increasing inhibition-zone diameter suggests that higher CA concentrations contributed to greater antibacterial activity of the film-forming solutions against *B. subtilis*.

The increase in inhibition with increasing CA concentration, particularly against *B. subtilis*, may be associated with the antimicrobial properties of CA in the film-forming solutions. Previous studies have shown that the antimicrobial activity of CA is influenced by pH and its ionization state, which can affect bacterial membrane integrity and cellular functions [18]. The gradual increase in the inhibition zone with increasing CA concentration suggests that CA contributed to the antibacterial response observed in the present formulations. The difference in response between the two bacterial strains may also be related to differences in their cell-envelope structures. *E. coli* is a Gram-negative bacterium with an outer membrane that can provide an additional barrier against antimicrobial compounds, whereas *B. subtilis* is Gram-positive and lacks this outer membrane. This structural difference may partly explain the greater inhibition observed against *B. subtilis* compared with *E. coli*.

Table 4. Antibacterial activity of PVA/BG films at different CA concentrations against *B. subtilis*, and *E. coli*

Samples	Diameter of inhibition zone in (mm); in Mean $\pm$ SD	
	<i>B. subtilis</i>	<i>E. coli</i>
Gentamicin (+ve)	17 $\pm$ 2.65	18 $\pm$ 2.65
PVA/BG	7 $\pm$ 1	6.33 $\pm$ 0.58
PVA/BG/CA1	7.33 $\pm$ 0.58	9.33 $\pm$ 3.21
PVA/BG/CA2.5	7.33 $\pm$ 0.58	9.33 $\pm$ 1.53
PVA/BG/CA5	10.67 $\pm$ 0.58	9.67 $\pm$ 0.58
P-values	1.71 $\times 10^{-5}$ <0.05	0.182193 >0.05

Results were reported as mean $\pm$ SD; $n=3$

* $P<0.05$ shows the significant difference by one-way ANOVA for all samples in each bacterial strain

Overall, the antibacterial response varied with CA concentration and bacterial strain. The presence of bioactive constituents in BG may contribute to the antibacterial potential of the formulations, while increasing CA concentration resulted in greater inhibition against *B. subtilis*. The 5 wt.% CA formulation showed the largest inhibition zone against *B. subtilis*, whereas the differences against *E. coli* were not statistically significant.

4. CONCLUSION

This study examined the effect of CA concentration on the structural, mechanical, thermal, and antibacterial properties of PVA/BG composite films. FTIR analysis showed changes in the intermolecular interactions within the film matrix following CA incorporation, while DSC results indicated changes in the melting and crystallization behaviour of the films. The tensile properties varied with CA concentration, with the control film showing the highest overall tensile properties. Among the modified formulations, the film containing 2.5 wt.% CA showed a better balance of tensile strength and Young's modulus. The antibacterial response varied with CA concentration and bacterial strain. The presence of bioactive constituents in BG may contribute to the antibacterial potential of the formulations, while increasing CA concentration resulted in greater inhibition against *B. subtilis*. Increasing CA concentration resulted in greater inhibition against *B. subtilis*, with the 5 wt.% CA formulation showing the largest inhibition zone. In contrast, the differences observed against *E. coli* were not statistically significant. Overall, the findings show that CA concentration influenced the properties of the PVA/BG films and highlight their potential for further development as wound-dressing materials. Further assessment of the final films, particularly their antibacterial performance and other properties relevant to wound dressing, is needed to better understand their suitability for practical applications.

5. ACKNOWLEDGEMENTS/FUNDING

The research was conducted using the facilities provided by Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM) Perlis Branch.

6. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

7. AUTHORS' CONTRIBUTIONS

Nurain Faqihah Badrul Hisham performed the experiment, analysed the data, wrote and revised the original article; Faiezah Hashim designed the study, provided the theoretical framework, mainly supervised the students, and reviewed the article; Sarina Mohamad co-supervised the students and reviewed the article; Nurul Aizan, Nor Hafizah Che Ismail and Siti Nor Din are responsible for review and editing the final manuscript.

8. DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT only to improve the language and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

9. DATA AVAILABILITY/SUPPLEMENTARY MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

10. ETHICS STATEMENT

The authors declare that this research did not involve human or animal subjects.

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