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Sujan Chowdhury (sujan@just.edu.bd)
Jashore University of Science and Technology
Nur Syaliani Binti Mohamed Rafflisman Zaidi
Universiti Tunku Abdul Rahman
Shee Keat Mah
Universiti Tunku Abdul Rahman

Research Article

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Posted Date: June 21st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1748886/v1

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[1,2] Sujan Chowdhury, [1]Nur Syaliani Binti Mohamed Rafflisman Zaidi, [1]Shee Keat Mah

[1] Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, Kajang 43000, Selangor, Malaysia

[2] Department of Chemical Engineering, Jashore University of Science and Technology, 1 Churamonkathi, Chaugachha Road, 7408, Jashore, Bangladesh.

Correspondence to:

Dr. Sujan Chowdhury
Assistant Professor
Department of Chemical Engineering,
Jashore University of Science and Technology,
1 Churamonkathi, Chaugachha Road, 7408,
Jashore, Bangladesh
Email: sujan@just.edu.bd

ABSTRACT

In this study, mulberry (*Morus nigra sp*.) leaves extract (MN) was used as a structure modifier and antimicrobial agent in poly(vinyl alcohol) (PVA) blend films. We prepared PVA/MN blend films by solution casting at various concentrations. The SEM micrographs showed that PVA_MN75 has a smooth and continuous cross-sectional morphology with better compatibility. Fourier-transform infrared spectroscopy results suggest that a specific concentration of MN in PVA films facilitates a physical interaction that improves mechanical and thermal properties. The tensile strength of the films increased from 1.89 MPa to 2.91 MPa after adding mulberry leaf extract. Furthermore, the films were assessed for their solubility in water (12.12-15.83 %), absorption (9.80-21.61 %) and moisture content (6.53-14.26), which further demonstrates that blend films exhibit lower water solubility. Moreover, the soil burial biodegradation test indicates that PVA/MN film biodegradability is strongly affected by its MN concentration. Upon soil burial, all films showed an increase in biodegradability of 29% as burial time has prolonged in both soil and compost for 37 days. Enhanced antibacterial activity has observed in the PVA/MN film-forming solution and can be considered as a promising substitute for polluting plastic packaging.

Keywords: Biopolymers, Biodegradable Films, Polyvinyl Alcohol, Biodegradation, Antibacterial.

INTRODUCTION

Nowadays, a technological breakthrough in the packaging is reflected on the development of food packaging, pharmaceutical, biomedical and other packaging industries. The industrial revolution has brought packaging materials to develop within the areas of edible, biodegradable, nanocomposite, active and intelligent packaging.[1-5] Flexible film packaging types describe any type of materials which is not rigid, but the term “flexible polymer” is often reserved for non-fibrous plastic polymers which are composed of molecular chains have long sequences of one or more species of atoms or groups of atoms linked to each other.[6,7] Poly(vinyl alcohol) (PVA) is a synthetic polymer carries the predictable properties of hydrophilic, biodegradable, tasteless, odorless, good mechanical properties and high ability to form packaging films.[8,9] Due to the predictable hydrophilic properties, PVA need to bind with other chemicals to promote a change in physical properties and to alter their hydrophilicity nature to hydrophobic properties, by removing hydroxyl groups between the polymer chains. Theoretically, all chemical compounds that are able to react with hydroxyl groups could be used as potential structure modifying (crosslinker) agent. PVA react with common crosslinking agents like dicarboxylic acid, tricarboxylic acid, dialdehyde, aldehyde, phenol group, carboxylic acid in ethylene glycol di-methacrylate and lactic acid to alter the hydrophilic properties.[10-16,5]

A molecule's size is crucial to the formation of a PVA-composite film because smaller molecules can readily fit into the void spaces within the polymer. Indeed, glyoxal and glutaraldehyde (GA) have an excellent potential for forming crosslinked composite films and exhibit antimicrobial properties, and are widely used in disinfectants.[17,13,16,14,15] Poly ethylene glycol diacrylchloride adapted the structure of PVA to offer tremendous biotechnology and biomedical potential, whereas butyl glycidyl ether (BGE) modified PVA for use as a surface sizing agent in

paper manufacturing. [18,19] The microbial activity also can be inhibited through other natural plant and herbs extraction, as reported neem, guava, indian acalypha, green chiretta and Holy basil leaves extraction enhanced the inhibition of microbial growth [20-22,7,23-29]. In addition, natural sources such as cinnamaldehyde and syzygium cumini leaves extract have been successfully applied to change the structure of PVA and at the same time minimize the inhibition of microbial growth of *Escherichia coli* species. [24,25] Moreover, turmeric and clove oil are widely known as effective antimicrobial agents against foodborne pathogen.[23,27]

Mulberry, or known as *Morus nigra* sp. leaves are widely used in Chinese traditional medicine to fight against certain disease and it has not yet been studied in food and packaging technology. *M. nigra* sp. is one of the mulberry species that can be found in western Asia. The mulberry leaves extract (MN) could be a potential agent to alter the structure of PVA and also an antimicrobial agent. The main constituents of *M. nigra* sp. are avones, steroids, essential oil and other constituents. It has been proved that MN possess anti-hypertensive, anti-hyperlipidemic, anti-hyperglycemic, anti-aging and antioxidant activities.[22,30] Beside of having pharmacological effects, the acidic compound in MN can act as a profiling and antioxidant potential.[20] Several studies also demonstrated that the chemical compounds obtained from mulberry leaves after the extraction process can contribute to antimicrobial activities based on the plant's species, harvest period and processing.[31,32] In light of the high potential of MN in food packaging technology especially in PVA filming, the present work has conducted to evaluate the influence of MN on the morphological, mechanical, thermal and water solubility properties of PVA films prepared by physical blending. Additionally, the biodegradability and antimicrobial test were performed to further access the potential of the films produced.

EXPERIMENTAL

Materials

PVA (99.8%-100% hydrolyzed) was purchased from Sigma Aldrich. Mulberry leaves were picked from garden in Putrajaya, Malaysia. Glycerol was supplied by Emsure. Methanol and hydrochloric acid (HCl) were provided by Merck. All the aqueous solutions throughout this work were prepared using deionized water.

Methods

Extraction of Mulberry Leaves

In a typical synthesis process, fresh mulberry leaves with a width of 10 to 15 cm were picked from their plant. The leaves were washed to remove any dust. Then, the mulberry leaves were dried in oven at 80 °C. After 5 h, the leaves were taken out from the oven and left cooled for 10 min. The dried leaves were grinded using a grinder until fine powder was obtained. Then, 20 g of leaves powder is poured into a conical flask containing 80:20 v/v of methanol and distilled water. The solution was put in the orbital shaker for 8 h at room temperature. After that, the solution was filtered using Whatman No.1 filter paper. The solid residue obtained after filtration were extracted twice with fresh solvent. The MN obtained were isolated from the solvent using a rotary evaporator at 45 °C under a reduced pressure. The MN was stored at 4 °C for further use.

Preparation of PVA/MN Blend Films

PVA powder was dissolved in 45 mL deionized water at 160 °C for 2 h. The PVA solution was left cooled for 5 min. Then, 1% of glycerol plasticizers was added into the solution by using a disperser (IKA, T-18 Digital Ultra-Turrax) for 2 min. After that, 0.65, 0.75 and 1 mL of MN was

added into the solution and was mixed for 3 min, and followed by the addition of the structure modifying agent obtained from evaporation process. Finally, HCl was added into the mixture for 3 min to increase the transparency of the solution. The solution was left to allow the escape of bubbles before being casted. The film was then casted using Doctor Blade and left dried overnight. The dried films were peeled off and placed into a desiccator. The thickness of the films was measured with a digital micrometer (Mitutoyo IP 65, Japan) for at least five positions of each random sample. All the PVA/MN blend films prepared were denoted as PVA_MN_x where, X is the content of MN added (0.65, 0.75 and 1 mL).

Morphology and Mechanical Characterization

The morphologies of the cross sections of the PVA/MN blend film produced were studied using a scanning electron microscopy (SEM) (Hitachi, S-3400N, Japan). A universal tensile tester (Instron, 5582Q4970) was used to measure the mechanical properties of the films, as per ASTM D882 standard discussed elsewhere. In the tensile strength study, 25.4 mm × 100 mm strips with a gauge length set at 50 mm was used and tested in triplicates. The spectral analysis was conducted using a Fourier-transform infrared spectroscopy (FTIR) (Thermo Scientific, Nicolet IS10) at range from 4000 cm^{-1} to 400 cm^{-1}. The thermogravimetric analysis (TGA) curves for the polymer samples were recorded using a TGA (Perkin Elmer, STA8000) by heating the films at rate of 30 $^{\circ}$C/min under nitrogen atmosphere with temperature range from 20 $^{\circ}$C to 800 $^{\circ}$C.

Moisture Content, Water Solubility and Water Absorption Properties

The moisture content (MC) of PVA/MN blend films was determined by measuring the weight loss of films, after drying in an oven at 105 $^{\circ}$C until a constant weight was obtained. Samples were tested in triplicates and results were expressed as an average of the percentage of MC of samples that was calculated using Eq. (1).

$$\text{MC}\ (\%) = \frac{W_{0,dry} - W_{1,dry}}{W_{0,dry}} \times\ 100\ \% \quad (1)$$

where $W_{0,dry}$ is the initial weight of the sample and $W_{1,dry}$ is the final weight of sample after drying process.

Besides, the water solubility (WS) of the prepared films in water was studied in the term of the loss of the dry matter of film after solubilized and immersed in water for 24 h at room temperature. After 24 h, the moisture on the surface of the films was removed and dried in oven until they maintained at a constant weight. The WS was calculated using the Eq. (2).

$$\text{WS}\ (\%) = \frac{W_{0,sol} - W_{1,sol}}{W_{0,sol}} \times\ 100\ \% \quad (2)$$

where, $W_{0,sol}$ is the initial weight and $W_{1,sol}$ is the final weight of the film after immersion and drying steps.

The water absorption (WA) of PVA/MN films was determined by immersing the films prepared in an acidic 0.2M of H_2SO_4 solution at room temperature for 24 h. The procedures were modified from method reported. After that, the moisture on the surface of the films was removed and the weight of the film was measured. The WA was calculated using the Eq. (3).

$$\text{WA}\ (\%) = \frac{W_{1,abs} - W_{0,abs}}{W_{1,abs}} \times\ 100\ \% \quad (3)$$

where, $W_{0,abs}$ is the weight before absorption and $W_{1,abs}$ is the weight of the swelled film.

Biodegradability Test

The soil burial test was used to evaluate the biodegradability of the films. The films were buried in composted soil at a depth of 10 cm with size of 20 × 20 mm. The soil with samples were left in laboratory and maintain at sparkling water with regular interval time. The degradation rate of the films was determined in terms of the weight loss of the sample over time.

Antimicrobial Test

To further access the capability of the prepared PVA/MN blend films in resisting the bacteria growth, their antimicrobial activity against *Escherichia coli* and *Legionella* bacteria were studied by using agar disk diffusion test, or alternatively known as Kirby-Bauer antibiotic test. The agar plate was first inoculated with microbial strains. A 5 mm hole was made on agar surface by using a cork borer and the PVA/MN film making solution was transferred carefully into the small hole. After that, the petri dish was incubated in an incubator at 37 $^{\circ}$C for overnight, and the microbial growth on the agar plate was observed.

RESULTS AND DISCUSSION

Morphology, Mechanical and Thermal Characteristics of the PVA/MN Blend Films

Figure 1 shows the SEM images of the cross section of the selected films. The SEM image of PVA/MN film showed compact and smooth structure. However, as increase the concentration of MN extraction, the image of cross sectional is varied. PVA_MN_{65} shows compact and rough cross section. Meanwhile, PVA_MN_{100} shows irregular pores or cavities distributed through the PVA matrix. These can be attributed to the lipid or creamy aggregation during drying steps. This also can prove that lipid of glycerol dispersed in the polymer matrix led to a discontinuous and loose structure in the matrix, compare with that PVA_MN_{75} that shows compact smooth and continuous

cross section. In facts, PVA in the composition itself makes the structure of films softer and more flexible. Obviously, a non-uniform morphology of the microstructure which can be caused by the phase separation and this non-uniform irregular pores distributed tends to reflect a decrease in intermolecular interaction between MN and PVA matrix that lead to the decrease in mechanical properties of the blend films.[26] In this study, the most important effect of MN when it presents at certain blend formulation, indicating the heterogeneous phase morphology. This phenomena has occurred owing to that it might be due to the aggregation of the extraction and plasticizer lead to the loss of integrity which disrupt the formation of intermolecular hydrogen bonding resulted in weak intermolecular interaction lead to increase the flexibility in the films.[25]

It was observed that the transparency of PVA/MN blend films slightly decrease when the amount of MN increased, particularly in the films consisting of 1.0 mL MN (PVA_MN_{100}). Conversely, this PVA/MN blend films remained transparent at high MN concentration.[24] Meanwhile, the film forming solution produced a homogeneous solution with transparent, odorless and easy to handle after drying steps. The thickness of the films was not sensitive to the changes of MN concentration, as presented in Table I. This due to release of alcohol and phase separation during the drying steps. However, the thickness of PVA/MN films increase when the content of MN reached to 0.75 (PVA_MN_{75}). Overall, the thickness of the films varied between 0.195mm and 0.082mm. A small value of standard deviation on all of the measurement demonstrated the films uniformity.

The mechanical properties of the cross-linked PVA film at different concentration are presented in Table I. From Figure 2, the tensile strength (TS) of the films decreases with increasing the concentration of MN extraction after it reach optimum content. The optimum content of MN extraction in the PVA/MN blend was optimized at 0.75 (PVA_MN_{75}) where it gives the maximum

properties of TS from 1.886 to 2.907 MPa and tensile modulus (TM) from 0.175 to 0.113 MPa. After 0.75 concentration of PVA_MN film, the tensile strength reduced. The decreasing TS (2.907 MPa to 1.608 Mpa) and increasing TM (0.113 MPa to 0.205 MPa) can be relate from the cross-sectional image of SEM where the film exhibits irregular pores distribution that lead to increase brittleness in the films. The increased TS from 1.886 MPa to 2.907 MPa is attributed to an increase in MN content. Which lead to an increase in the cross-linkage between the MN extraction and PVA matrix through intermolecular –OH and hydrogen bonding. A similar study had suggested as increase in tensile strength (TS) with decreasing tensile modulus (TM) is due to the enhancement of structural bonds in the polymer network which it reduce the brittleness properties of PVA polymer.[33,34] This study found that the cross-linking and concentration of MN extraction affected TS and TM value of cross-linked films. The cross-linking reaction allowed the MN extraction to combine with PVA which improves mechanical properties.

Additionally, TGA was conducted to study the thermal stability of the different concentration of the MN in PVA plastic films. As illustrated in Figure 3(A), the PVA/MN blend films incorporated with different concentration of MN showed as increasing the concentration of extraction, the region of mass loss will shift towards higher temperature range. The initial mass loss of PVA_MN_{65} films in the region from 50 to 80 $^{\circ}$C resulted from the evaporation of water. Meanwhile, as increase the concentration of extraction the evaporation of water take place at region from 50 to 140 $^{\circ}$C. It is know that the second thermal degradation is between 250 and 420 $^{\circ}$C is primarily due to the pyrolysis of PVA. On the other hand, when the concentration of MN increased from 0.75 until 1.0, the onset decomposition temperature was about 300 $^{\circ}$C. This is shown that the thermal decomposition of the films shifted toward a higher temperature range compared to low extraction concentration PVA film. Improved thermal stability in the PVA/MN

blend film was observed where the third stage mass loss occurred above the region of 400 °C.[24]. This enhancement in the thermal stability and change in the decomposition patterns of the films may resulted from the structural alternation caused by the interaction of the hydroxyl group of the PVA macromolecules and the surface phenolic group of MN.

A comparison between sample compositions was shown in Derivative thermo-gravimetric (DTG) peak of Figure 3(B). The resulted data shows that the addition of MN extraction increase and improves its degradation temperature. Through DTG peaks clearly can be seen that, decomposition temperature of PVA films improves considerably in presence of glycerol and MN extraction as the amount of the extraction increase until it reaches certain sample compositions. This is due to new hydrogen bonding between the molecule of PVA, glycerol and incorporation of the natural extraction. The increased DTG peak intensity and decrease peak broadness indicate that there was a smaller number of –OH group present in the system of PVA matrix film incorporated with glycerol and MN extraction. The lowest and narrow peak intensity were obtained from sample of PVA_MN_{75} shows lower degradation rate and better thermal stability compared other sample and it were further enhanced by crosslinking of MN extraction. Which clearly indicates that the hydroxyl group were engaged in the formation of hydrogen bonds between the polymer chains and incorporated filler to make a strong interface between the polymer chains. The remaining of hydroxyl group were participated in the crosslink reaction where the restricted chain mobility in the polymer chain keeps the stiff and rigid.[35]

Aiming to gain better understanding for the change of properties of PVA/MN blend films, the functional groups present in the PVA/MN films were identified through FTIR spectrum, as shown in Figure 4. The important peaks were given in Table S1 in Supporting Information. The polymeric -OH stretching appeared between 3262 cm^{-1} and 3263 cm^{-1}, where this exhibited broad band gaps

indicates the inter- hydrogen bonded O-H stretching vibration of the hydroxyl group.[36,37] In the PVA/MN blend film, -OH stretching vibration of PVA slightly increased to higher value 3262 cm^{-1} and 3263 cm^{-1}, meaning that there is strong intermolecular interactions between the PVA matrix and MN. This broad absorption also might due to to a rise from the O-H stretching frequency of PVA and water -OH group.[38] Basically, the free hydroxyl functional group has a broad peak between 3600 cm^{-1} and 3650 cm^{-1} and this broad peak will shift to peak between 3200 cm^{-1} and 3500 cm^{-1} when there is -OH group is engaged between the matrix and reinforcement or other chemical in the formation of hydrogen bond.[39] The alkyl C-H stretching in CH_3, CH_2 and CH group and bending band from backbone chains of the matrix and chemical compound occurred at 2928 cm^{-1} and 1423 cm^{-1}.[36,25,35,40,37] It is also stated that between 2928 cm^{-1} and 2929 cm^{-1} band gap there is a presence of methyl C-H asymmetric stretching. The presence of this group was confirmed by R. Jayasekara et al. where at peak 1324 cm^{-1} attributed to the C-H stretching, bending and C-O stretching of PVA.[38] The small hump at 1650 cm^{-1} is attributed to C=C stretching of that aromatic compound contained in the PVA/MN blend films. Bound of water occurred at peak 1651 cm^{-1} due to the presence of water in the films.[38,35] Moreover, according to Murat Simsek et al., a presence of band gap between 1715 cm^{-1} and 1595 cm^{-1} can be due to the symmetric –C=O stretching from –COOH and –COOR (saturated ester) group.[37] Next, the absorption band occurred at 1040 cm^{-1} is assigned to the C–O stretching of PVA/MN structure.[24,17,41] The most appreciable changes were observed in the FTIR spectrum of PVA/MN blend films where the formation of absorption peak between 1410 cm^{-1} and 1290 cm^{-1} is the primary or secondary -OH stretch, phenol and tertiary alcohol OH bend. Furthermore, the cross-linking function was also confirmed by the reduction of the relative intensity of hydroxyl bond in the cross-linked film. Hence, the results indicated that there exists strong interaction between PVA/MN due to the

hydrogen bond and -OH group present in the PVA and MN extraction which supported by an improvement in the mechanical properties.

Moisture Content, Water Solubility and Water Absorption Properties of the PVA/MN Blend Films

As shown in Figure 5(A) and summarized in Table II, the water content in PVA/MN film increasing as increase the concentration of MN until it reaches concentration of 0.65, then it starts to decrease. This finding is attributed to the hydrophilic nature of the MN extraction and PVA polymer itself due to interaction with hydroxyl group and removing of water molecule resulted from the crosslink mechanisms. Moreover, glycerol and water molecule may act as a natural plasticizer to allow the PVA to be more flexible than its characteristics as rigid and hard polymer when in a complete dry form.[9] WS reflected the water resistance, and it may give an idea with respect to films applications in packaging for food products. A very low water solubility is required for food products, especially in contact with food product with high water activity that require packaging integrity under ambient conditions.[41,28] The results was illustrated in Figure 5(B), which cross-linked films with varied concentration of MN effected the resistance of films through water. PVA_MN_{75} shows less solubility of film towards water this may due to the cross-linked of the extraction compound with PVA matrix which reduced the -OH group for water to combine with the compound. It can be concluded that this natural extraction had an effective water resistance, which most likely due to the establishment of hydrophobic bind and improvement in rigid molecular for nation in the film thus increasing the resistivity of water.

WA is a measure of the amount of water absorption when material is exposed to water. As shown in Figure 5(C), the PVA/MN film immersed in acidic solution gave the lower WA values where it

keeps decreasing as the natural extraction content increase. The phenomenon might be attributed to the presence of large molecules in acidic solution making the diffusion process into film matrix to be slow and producing in lower values of absorption kinetic parameters.[42] Water absorption drop slightly after it reach 0.65 MN extraction content which by means it reach suitable concentration of incorporation with extraction because of the hydroxyl group of PVA may be cross-linked fully with the extraction and other compound in the films which it produced compact crosslink structure which unable for the acidic molecule to diffuse in the matrix of films.

On the other hand, at concentration of 0.65, it shows higher moisture absorption which it may due to some of the glycerol in films that act as plasticizer contain excess hydrophilic group in which these water molecules interact with the macromolecule of glycerol by means of hydrogen bonds that resulting in high moisture absorption. This phenomenon can be stated that water molecule and excess hydroxyl group of glycerol can constitute a problem due their stronger plasticizer effect in the films matrix and modifying the physical properties of the film.[21]

3.4 Biodegradability and Antimicrobial Behaviors of the PVA/MN Blend Films

Degradability of polymer is a crucial functionality for packaging applications. The soil burial test is an assessment that gives a realistic environment, where the soil temperature, humidity, type and the amount of microorganisms are in less control and differ with seasons.[21,28] The physical changes of films during soil burial test as in Figure 6. The weight loss of PVA/MN films occurred in soil and compost respectively. The biodegradability increases up to 29% as the burial time increased in both soil and compost for 37 days. All of the films in soil and compost degraded constantly in first 13 day and degraded rapidly for the next 8 days. This continuous and rapid

degradation was due to the composting process that occurred in two main stage as stated by previous research where this stages are active composting stage and a curing period.[9,29,43-45] In the 1st stage, the temperature rose and remained elevated as there is still available oxygen which resulted in strong microbiology activity. In the 2nd stage, the temperature decreasing but the film continued to compost but at a slower rate. In the both soil and compost, the PVA_MN_{100} sample showed the highest weight loss while PVA_MN_{65} shows the lowest weight loss. This finding might be attributed to the excess hydrophilic in glycerol and MN which lead to highest degradation rate. Moreover, PVA itself have biodegradability properties owing to its hydrolysable, exhibited a low resistance against soil burial degradation. The addition of compost help in increasing the degradation rate. Figure 6 shows the weight was slightly lower for duration of 22nd to 37th days However, the composting is still continuing and did not stop at a particular day. Instead of, it continued slowly until the all the remaining nutrient was consumed by the survived microorganisms and eventually nearly all of the carbon had been converted into carbon dioxide.

The antimicrobial activities of the PVA extraction film-forming solution incorporated with MN at different MN concentration were analyze by disc diffusion methods against *E. coli* and *legionella*. The inhibition activities were measured by the diameter of inhibition zone. The results are shown in Figure 7 with the inhibition zone of the microbial in the Table III. From overall, the PVA film forming incorporated with 0.75 concentration of MN (PVA_MN_{75}) inhibited excellent inhibition zone of 12.17 mm. As increased concentration of extraction PVA_MN_{100} films, shows least effective towards *E. coli* which the inhibition zone is 10.33 mm. In other hand, same pattern of results can be seen in the inhibition of PVA_MN film forming solution towards *legionella*. Where the highest inhibition zone take place at 13.83 mm for PVA_MN_{75}.This is shown that PVA_MN_{75}

is the optimum concentration for antimicrobial activity compared to other concentration and can be considered as a promising candidate for plastic packaging.

CONCLUSION

The most optimum composition of PVA and MN in making blend film was at PVA_MN_{75}, where it shows improved tensile strength (2.907MPa), tensile modulus (0.113MPa), high thermal degradation, moisture content (13.44 %), water solubility (12.16 %), water absorption (16.80 %) with smooth and compact film morphology. The PVA_MN_{75} film resulted in an appropriate film degradation towards soil and good microbial inhibition towards *E. coli* and *Legionella* species. Hence, through this study we can conclude that the mechanical properties of PVA have been improved by the addition of MN as well as the water solubility properties of the films were decreased. The improved properties of PVA film with the use of MN showed superior properties for food packaging application. In addition, MN contributes in the crosslinking reaction and exhibited good antimicrobial properties and maybe suitable candidate for plastic packaging.

Acknowledgments

This research was supported by UTARRF scholarship (IPSR/RMC/UTARRF/2016-C2/50S) project (vote number 6200/S74) and 6200/M26.

Author Contributions Statement

Dr. Sujan Chowdhury and Dr. Mah Shee Keat encouraged Nur Syaliani Binti Mohamed Rafflisman Zaidi to investigate the overall work. Dr. Sujan Chowdhury supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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Figures

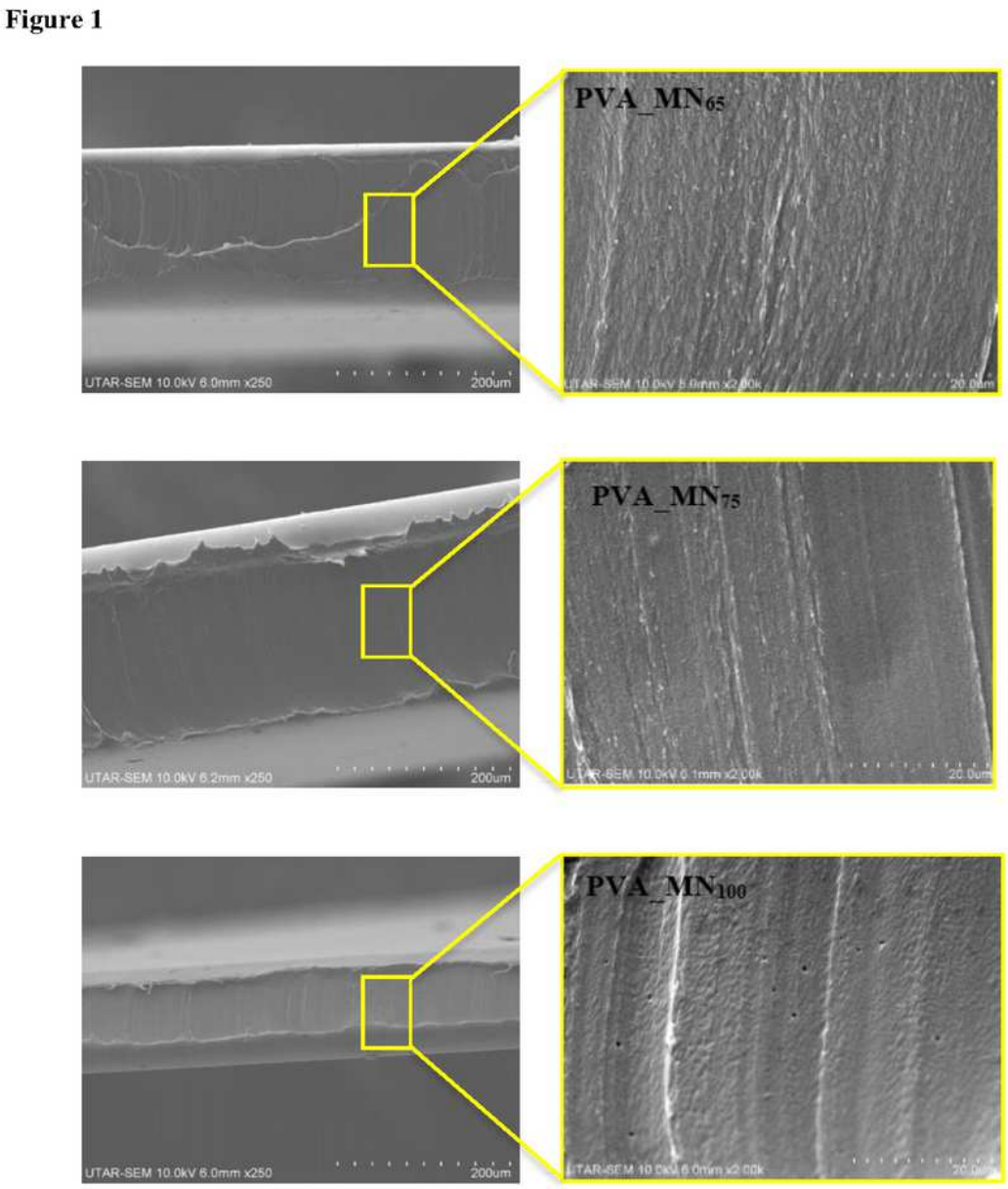

Figure 1

SEM images of the cross section of the PVA/MN blend films at different MN content.

Figure 2

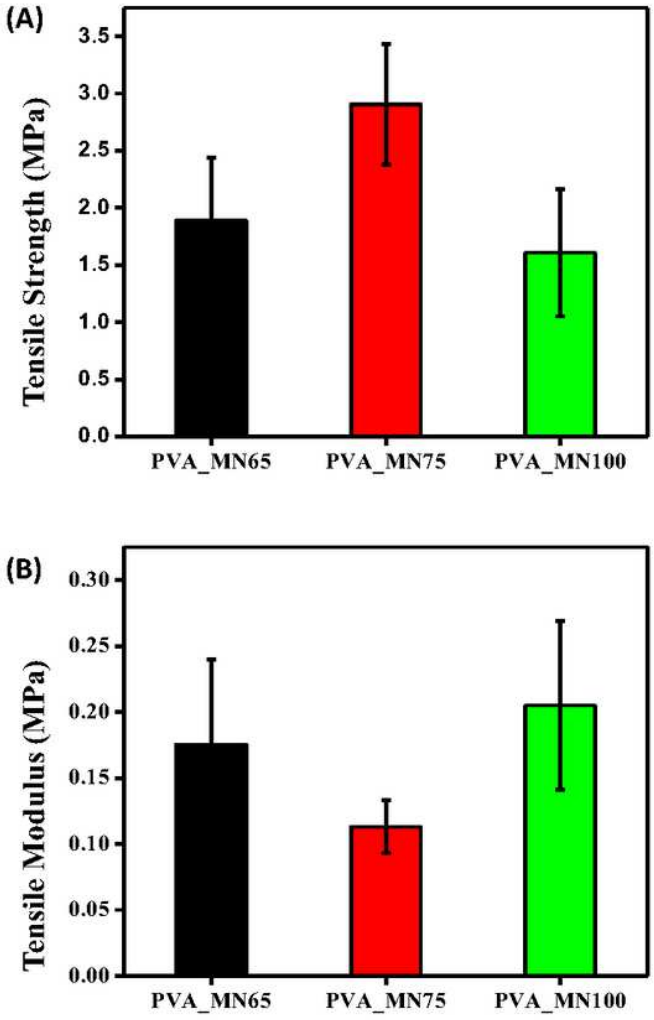

Figure 2

Mechanical properties of the PVA/MN blend films at different MN content.

Figure 3

(A) TGA and (B) DTG of the PVA/MN blend films at different MN content.

Figure 4

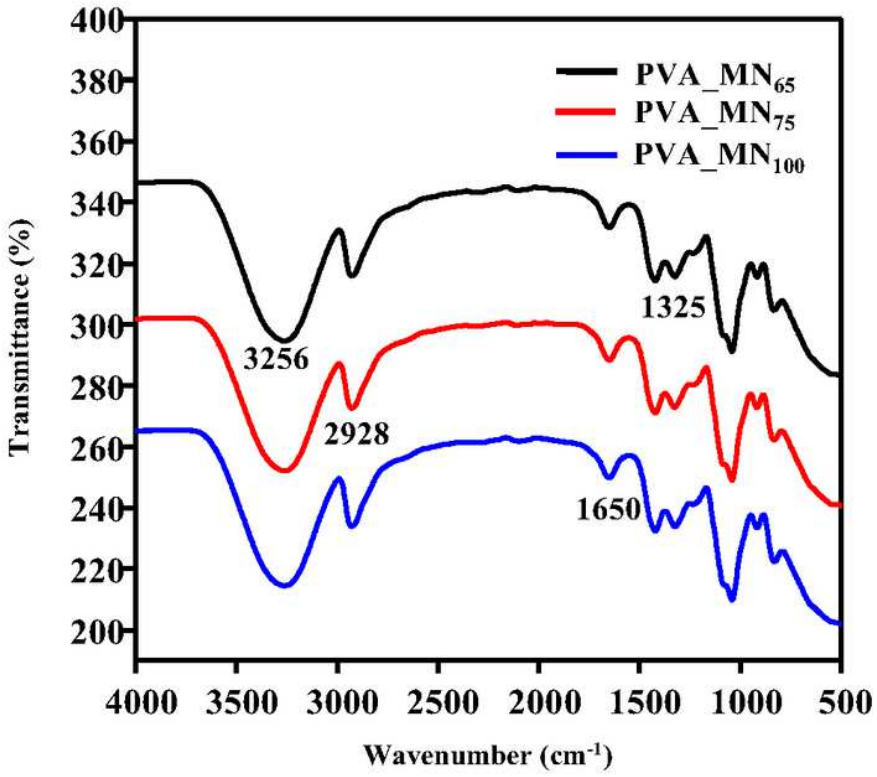

Figure 4

FTIR spectrum of the PVA/MN blend films at different MN content.

Figure 5

(A) MS; (B) WS; and (C) WA of the PVA/MN blend films at different MN content.

Figure 6

Images of the PVA/MN blend films at different MN content for biodegradability test.

Figure 7

Images of the inhibitory zone of the agar plates incubated with (a) Escherichia coli and (b) Legionella bacteria with PVA/MN film making solution at different MN content.

Supplementary Files

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- Table.pdf
- SupportingInformation.pdf