Effect of banana peel waste concentration and mixing rate to the tensile strength of polyvinyl alcohol/banana peel waste composite film: optimization study via statistical tool

Q H Ng, V Kalaiarasi, Y P Teoh, Z X Ooi, S H Shuit and C Y Low

1Frontier Materials Research, Centre of Excellence (FrontMate), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
2Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
3Department of Petrochemical Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia.
4Department of Chemical Science, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti Bandar Barat, 31900 Kampar, Perak, Malaysia.
5Department of Chemical Engineering, Lee Kong Chian, Faculty of Science and Engineering, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Cheras 43000, Kajang, Selangor.

E-mail: teohyp@utar.edu.my

Abstract. Plastic bags are essential in human’s life on a daily basis. Most of the packaging materials used today are petroleum based manufactured polymers which are non-biodegradable. These polymers contribute to the landfill and take millions of years to decay. Decomposition of these plastics would also release harmful gases into the environment. On the other hand, readily available degradable plastics are expensive. Therefore, the purpose of this research is to produce a biodegradable film as a substitution for the commercial biodegradable plastics to overcome such problem. A series of biodegradable polymer films derived from polyvinyl alcohol (PVA) embedded with banana peel waste (BPW) was prepared by solution casting method. The BPW was introduced as a promoter of biodegradability of the PVA. It was found that as the amount of BPW increases, the colonies of the fungal growth on the film showed a corresponding increase, indicating higher biodegradability of the PVA composite film. The blended films with different compositions of BPW were evaluated for their tensile properties using one-factor-at-a-time (OFAT) technique and hence optimized via response surface methodology (RSM). The tensile strength of the PVA/BPW films (32.52–46.97 MPa) was found to be lower than those of unfilled PVA film (80.30 MPa). The best composition of BPW filler in this study was found to be 5.1% with respect to PVA and it is compatible to be used as a film in daily uses.

1. Introduction

The rapid economic growth in developing countries has prompted to significant increase of solid waste. Along with the economic growth, the rate of acceleration of municipal solid waste has increased year by year. In fact, data showed that the total amount of solid waste generated in the year 2010 was 2000 tonnes per day or approximately 730,000 tonnes per year [1]. The quantity of waste comes from dwelling
premises reaches as many as 1.65 tonnes per day. Furthermore, 21% of total solid waste generation was attributed by plastic waste which required years to be degraded [2]. Therefore, further action needs to be taken to reduce the amount of plastic mounted in the future.

Plastic is a material that produced from petroleum. It has been generally utilized in packing, agriculture and development materials. In spite of the undeniable advantages of plastic, the negative effects of these packaging film is being chemically stable, thus having low degradation rate [3]. Synthetic biodegradable polymers have been vastly utilized as part of the production of plastics in the industry as an alternative to solve the plastic waste disposal problem. These biosynthetic polymers can be grouped into three categories, including biopolymers, which are alternate polymers of regular sources such as protein and cellulose, engineered biodegradable polymers, which are known as natural-based polymers that made up of oil and the engineered biopolymers which experience physical or concoction changes to fasten the rate of degradability. The engineered biopolymers such as polyvinyl alcohol (PVA) have been utilized in the past few years [4].

PVA is a chemical biopolymer that allows film production by various methods such as blow extrusion, hot extrusion and solution casting. Typically, the PVA film is commercially produced by solution casting techniques [5]. This type of polymer has good resistance towards chemical and thermal attacks. Its high tensile strength enables its utilization in various applications such as packaging material, adhesives, dip coating, glues and plunge covering [6]. The mechanical properties of the plastics are crucial. Besides, it is also an important tool for an engineer to identify any unknown and reproducible characteristics of the polymers of interest [7]. The mechanical properties determine the quality of the polymer and its ability to withstand stress. Measuring these properties is extremely important for plastic production, according to the needs of the plastic in the market [8]. Even though the PVA film has the potential to replace the petroleum-based plastic, the high cost of PVA production make it hard to compete with the low cost petrochemical polymer such as polypropylene and polyethylene in plastic production [9]. Thus, a low cost PVA production needed due to ecological benefits. Hence, the incorporation of organic waste into synthetic biodegradable polymers might be the potential solution.

Banana is scientifically known as Musa sapientum. It is ranked fourth as one of most common food sources in the world. Banana is the most important food followed by milk, corn and rice [10]. Banana is widely grown tropical fruits especially in India, Indonesia and Malaysia. On top of being consumed directly, banana can be processed into other products such as jam, chips and other snacks. However, banana peel contributes to a large amount of solid waste, especially upon harvest and being consumed. According to Fernandes et al. [11], each cycle of banana production contributes four times of waste and it is estimated to be 4 tonnes of banana peel waste (BPW) generation per month in Malaysia. BPW consists of 30% to 40% of the total weight of the whole banana. In fact, BPW is rich in nutrients and organic minerals. Therefore, this study focused on the blending of PVA with BPW to enhance the biodegradability of the PVA film and the effect of BPW incorporation to the tensile strength of PVA film.

2. Materials and Methods

2.1. Raw Materials
Banana species of Musa sapientum was obtained from areas around Padang Besar, Perlis. PVA was purchased from Sigma-Aldrich (M) Sdn. Bhd with fully hydrolysed, average molecular weight of 89,000-98,000 g/mol and a density 1.269 g/cm³.

2.2 Preparation of Banana Peel Waste (BPW) Powder
Banana skin was peeled off and washed using distilled water and followed by cutting it into smaller pieces (2-3 cm). It was then dried in the oven for 50°C overnight before ground into fine powder in size of 80 mesh.

2.3 Synthesis of Polyvinyl Alcohol/Banana Peel Waste (PVA/BPW) Film
The amount of PVA/BPW flour was prepared based on the formulation as shown in Table 1. Initially, 80 ml of distilled water and PVA were blended homogeneously in the Erlenmeyer flask and heated at 80°C for 30 minutes. BPW filler was then added into PVA solution and continued heating and blend homogeneously for another 2 hours. The solution mixture was poured onto a sterile glass plate. The solution was dried at room temperature for overnight before drying in the oven at 37°C for 30 minutes to ensure complete drying.

Table 1. Formulation for the preparation of PVA/BPW film blend.

| Blend | PVA (% weight/volume) | BPW (% weight/volume) |
|-------|----------------------|----------------------|
| A     | 100                  | 0                    |
| B     | 90                   | 10                   |
| C     | 80                   | 20                   |
| D     | 70                   | 30                   |
| E     | 60                   | 40                   |

2.4 One-factor-at-a-time (OFAT) Method
The effects of the physical conditions for the PVA/BPW film were investigated by employing OFAT technique. In this research, the main two parameters (the mixing rate of the PVA/BPW blend film (low, medium and high) and the concentration of BPW flour (0-40% w/v)) were studied. In each experiment, only one factor was varied while other factors were kept constant. All these experiments were performed in five replicates and the average values were recorded.

2.5 Optimization Study using Response Surface Methodology (RSM)
The mixing rate and BPW concentration were optimized using response surface methodology (RSM) via central composite design (CCD). The chosen parameters and their highs and low value were shown in Table 2. The response measured would be tensile strength (unit: MPa).

Table 2. List of factors and their levels for CCD.

| Factors                        | Range and Level |
|--------------------------------|-----------------|
| Composition of BPW (% w/v)     | Low (-1)        |
|                                 | Medium (0)      |
|                                 | High (+1)       |
| Mixing rate (rpm)              | L               |
|                                 | M               |
|                                 | H               |
*The magnetic stirrer available in laboratory can give indication as L: low, M: medium and H: high.

2.6 Tensile Strength Analysis
The tensile test was conducted using texture analyzer machine (AMTG). The crosshead speed was set at 20 mm/min. The mean thickness of this sample film was approximately 0.10 mm. All these examinations were carried out at room temperature and the mean value of five replicated tests for each composition was recorded.

2.7 Swelling Analysis
For swelling analysis, the pure PVA film was prepared and dried to constant weight (W1), followed by dipped in distilled water for 24 hours at room temperature. Then the sample was unwrapped from the water, surface water was removed gently by tissue paper and weighed (W2). The swelling ratio than calculated using Eqn. (1).

\[
Swelling ratio = \frac{\text{Weight of swelled sample}}{\text{Weight of dry sample}} = \frac{W2-W1}{W1}
\]

3. Results and Discussion
3.1 PVA/BPW Biodegradable Polymer Film

Figure 1 portrayed the significant colour changes in the preparation of PVA/BPW biodegradable polymer film. Pure PVA film is transparent and clear as presented in Figure 1(a). Meanwhile, as the amount of BPW filler increased, the colour intensity of the film increased. The BPW is coarsely dispersed in the PVA matrix, thereby causing the surface of the PVA/BPW films to be brittle and rougher when compared to the pure PVA film.

![Figure 1. Preparation of PVA/BPW film according to difference formulation: (a) 0% BPW, (b) 10% BPW, (c) 20% BPW, (d) 30% BPW and (e) 40% BPW.](image)

Biodegradable polymers can be degraded under specific environmental conditions by allowing microorganisms to break down their molecular chains of the polymer. Various biodegradable polymers that have been synthesized showed the capability to be degraded by certain microorganisms and enzymes [12]. Figure 2 showed the presence of growth of fungal on the PVA/BPW films. According to Briassoulis [13], this type of biodegradable polymer is classified under carbon polymer.

Based on observation through Figure 2, the rate of biodegradability was proportional to the amount of BPW. As the amount of BPW increased, the colonies of the fungal growth on the film also increased (Figure 2). This observation was due to the higher amount of nutrients available for the growth of the fungi as the amount of incorporated BPW increased. In contrast, no growth of fungal on the pure PVA film was observed even after 5 days (Figure 2 (a)). This phenomenon occurred as less nutrients available for the growth of fungi on the pure PVA film. Therefore, the biodegradable polymer film derived from PVA/BPW is clearly enhanced.
3.2 Effect of BPW Concentration to Tensile Strength of PVA/BPW Film
In the investigation of the effect of BPW concentration to tensile strength of PVA/BPW film, the concentration of BPW varied in the range of 10 to 40% (w/v), while the mixing rate remains constant at medium speed during the solution casting process. Figure 3 clearly depicted the significant changes in the tensile strength of PVA/BPW film with different BPW composition. In this study, the highest tensile strength obtained in this study was recorded as 36.29 MPa for 10% (w/v) BPW/PVA film. Oppositely, the film with 40% (w/v) BPW showed drastically reduced in tensile strength, with the value of only 1.63 MPa. The drastic drop of tensile strength probably reflected the weak intermolecular of hydrogen bonding between the PVA and BPW. In addition, the coalesced and coarsely dispersed BPW filler granules could reduce the compatibility between PVA and BPW filler and thus lower the tensile strength of the BPW incorporated PVA [14].

3.3 Optimization Study on Tensile Strength of PVA/BPW Film
Results from OFAT analysis indicated that the composition of BPW at 10% (w/v) yielded the highest tensile strength. Hence, it was chosen as the central point for further optimization study by using RSM via CCD. Accordingly, the range of composition of BPW was set at 5-15% (w/v) and the mixing rate
was remained as low, medium and high. Table 3 presented the CCD matrix with tensile strength as a response.

![Figure 3. Tensile strength (MPa) against the concentration of BPW film.](image)

**Table 3.** CCD matrix with tensile strength as a response.

| Run | Composition of BPW (% w/v) | Mixing rate | Tensile strength (MPa) |
|-----|----------------------------|-------------|------------------------|
| 1   | 5                          | L           | 34.13 ± 0.04           |
| 2   | 15                         | L           | 32.52 ± 0.01           |
| 3   | 5                          | H           | 46.08 ± 0.05           |
| 4   | 15                         | H           | 39.45 ± 0.06           |
| 5   | 5                          | M           | 36.54 ± 0.13           |
| 6   | 15                         | M           | 46.11 ± 0.04           |
| 7   | 10                         | L           | 45.76 ± 0.09           |
| 8   | 10                         | H           | 46.35 ± 0.07           |
| 9   | 10                         | M           | 45.79 ± 0.00           |
| 10  | 10                         | M           | 41.67 ± 0.05           |
| 11  | 10                         | M           | 37.14 ± 0.11           |
| 12  | 10                         | M           | 46.97 ± 0.01           |
| 13  | 10                         | M           | 41.02 ± 0.05           |

*The magnetic stirrer available in laboratory can give indication as L: low, M: medium and H: high.

The overall interaction of parameters and response can be understood by using the three-dimensional (3D) quadratic profiles for tensile strength as shown in Figure 4. The presence of plateau in the model depicted the strong interaction between the composition of BPW and mixing rate on tensile strength. The 3D surface resembled a saddled shape with a clear maximum peak located at the point of 46.97 MPa tensile strength at the composition of BPW of 5.1% (w/v) and mixing rate of the solution of medium speed. Following that, the graph showed that the tensile strength fluctuate as the composition of BPW is varied. This result was in good agreement with report done by Ooi *et al.* [15], where the tensile strength of film fluctuates as the composition of tropical fruit waste varied. In addition, the best mixing rate is observed at medium speed. The tensile strength of the film was found to decrease at high mixing rate owing to the disturbance of dynamic equilibrium of the solution. In addition, vigorous stirring may cause bubble formation in the solution. The trapped bubbles served as the stress concentrator and initiate
crack when external force was applied on it. On the other hand, at low stirring speed the dynamic equilibrium between PVA and BPW is slower than at higher stirring speed [6], causing non-ideal mixing of the solution.

Furthermore, an additional of 5.1% (w/v) of BPW into PVA matrix caused a significant 52% reduction in tensile strength of pure PVA (81.72 MPa). Even though the tensile strength of the composite PVA film was reduced after the incorporation of filler, the remaining tensile strength (46.97 MPa) is still meeting the required standard tensile strength of a plastic bag (~15 MPa).

![Figure 4](image.png)

**Figure 4.** Three-dimensional representation of the interaction between mixing rate and composition on tensile strength.

4. Conclusion

PVA/BPW biodegradable polymer film were successfully produced via solution casting method with water as solvent. The BPW concentration governed the water properties and biodegradability of the PVA/BPW blended films. Higher concentration of BPW in PVA/BPW blended film caused higher colonization of fungi, indicating higher biodegradability of the film. The tensile properties were found to be inversely proportional to the BPW content in PVA in which when the BPW content in PVA increased, the tensile strength of the PVA film decreased. OFAT analysis indicated that the highest tensile strength of PVA/BPW film can be obtained in 10% (w/v) of BPW concentration and medium speed of mixing rate. Further optimization of BPW concentration using RSM coupled with CCD indicated that the optimum concentration of BPW and mixing rate were 5.1% (w/v) and medium rate, respectively. The tensile strength of the PVA/BPW produced under this optimum condition was 46.97 MPa.
References
[1] Budhiarta I, Siwar C and Basri H 2012 *Int. J. Adv. Sci. Eng. Inf. Technol.* 2 16-21
[2] Mamat R and Chong T 2007 *Dev. Sustainability* 4 5-7
[3] Sreedhar B, Chattopadhyay D, Karunakar M S H and Sastry A 2006 *J. Appl. Polym. Sci.* 101 25-34
[4] Sedlářík V, Saha N, Kuřitka I and Sáha P 2007 *J. Appl. Polym. Sci.* 106 1869-79
[5] Lin S-Y, Chen N-T, Sum S-P, Lo L-W and Yang C-S 2008 *Chem. Commun.* 4762-4
[6] Ooi Z, Ismail H, Abu Bakar A and Aziz N 2011 *J. Vinyl Addit. Technol.* 17 198-208
[7] Wan Y, Luo H, He F, Liang H, Huang Y and Li X 2009 *Compos. Sci. Technol.* 69 1212-7
[8] Sin L T, Rahman W, Rahmat A and Khan M 2010 *Carbohydr. Polym.* 79 224-6
[9] Ramaraj B and Poomalai P 2006 *J. Appl. Polym. Sci.* 102 3862-7
[10] Vandana P, Masih H, Kumar Y, Singh A K and Peter J K 2014 *Int. J. Bioinformatics Biol. Sci.* 2 179-88
[11] Fernandes K, De Carvalho V and Cal - Vidal J 1979 *J. Food Sci.* 44 1254-5
[12] Feng S, Chen H, Liu Y, Huang Z, Sun X, Zhou L, Lu X and Gao Q 2013 *Sci. Rep.* 3 1838
[13] Briassoulis D 2004 *J. Polym. Environ.* 12 65-81
[14] Morreale M, Scaffaro R, Maio A and La Mantia F 2008 *Compos. Part A: Appl. Sci. Manuf.* 39 503-13
[15] Zhong O X, Ismail H, Abdul Aziz N A and Abu Bakar A 2011 *Polym. Plast. Technol. Eng.* 50 705-11

Acknowledgements:
The authors gratefully acknowledge the financial support from UTARFF project and Universiti Malaysia Perlis.