The Effect of The Addition Of Polyvinyl Alcohol (PVA) Concentrations on the Characteristics of The Carboxymethyl Cellulose (CMC)-Poly (Acrylic Acid) Hydrogel Superabsorbent as a Planting Medium

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ABSTRACT

Superabsorbent hydrogel is a hydrophilic network that can absorb and bind large amounts of water but is insoluble in water. The hydrogel can be applied in various fields, including medical applications, planting mediums, and waste absorbers. One type of hydrogel that has been widely developed is Carboxymethyl Cellulose (CMC) based hydrogel. However, CMC-based hydrogels still have several shortcomings, namely mechanical properties and low water absorption. In this study, a superabsorbent hydrogel was synthesized from CMC and acrylic acid with the addition of PVA and citric acid as a cross-linking agent and ammonium persulfate as an initiator. This research was conducted to determine the effect of PVA on the characteristics of the CMC-Poly(Acrylic Acid) hydrogel. The variation of the concentration of PVA used was 0% to 2.5% (w/v). The analyzed characteristics include gel fraction, swelling ratio, and mechanical properties (tensile strength and elongation). The results showed that adding PVA decreased gel fraction from 60.35% to 48.68% and increased the swelling ratio from 719% to 895%. The mechanical properties of hydrogel also increased by increasing the concentration of PVA, as seen in the tensile strength value (0.365 MPa to 2.165 MPa) and the percent elongation (13.96% to 30.82%). The results of the FTIR spectrum showed the presence of the OH functional group at the absorption wave number 3284.42 cm^{-1}, and a new absorption band appeared due to the cross-linking at the wave number 1303.88 cm^{-1} (C-C group).

1. Introduction

The technology of material development, especially hydrogel, is currently growing rapidly. One of the uses of hydrogel is as a planting medium. In agriculture, an inadequate amount of moisture in plants leads to untimely leaf fall, reduced chlorophyll content, and reduced seeds and fruits produced in plants [1, 2]. Therefore, it is necessary to carry out good water management to maintain humidity and increase water storage capacity in the soil.

A hydrogel is a three-dimensional cross-connective tissue structure of a polymer chain and can work as a store of water around the roots of plants. Hydrogels can absorb water up to thousands of times their size [3].

Due to the characteristics of the hydrogel, there is a considerable possibility of retaining irrigation water and rainwater so that it can be stored and released slowly (through the diffusion process) for the needs of plants in the long term. The hydrogel can reduce the danger of drought in plants by acting as a water store and releasing water slowly.

The superabsorbent hydrogel can be made from derivatives of natural materials such as starch, collagen, flour, gelatin, cellulose, chitosan, dextran, and alginate, which have a hydrophilic group and have a high-affinity power to water or synthetic materials. One of the natural polymers that can be used is CMC. This polymer is easy to absorb water, non-toxic, biocompatible, and biodegradable [4].

However, cellulose superabsorbent hydrogels exhibit poor mechanical properties, so some efforts are needed to improve the mechanical properties of hydrogels and reduce the possibility of damage to superabsorbent hydrogels [5].

Polyvinyl Alcohol (PVA) is a synthetic polymer with high tensile strength and flexibility. PVA has hydrophilic properties so it can improve the properties of chitosan gel by lowering the gelation time and increasing mechanical strength [6].

In this study, it is hoped that the addition of PVA to the superabsorbent hydrogel CMC-Poly (Acrylic Acid) can improve the mechanical strength and inflate ability of superabsorbent polymers. This increase in characteristics is expected to meet the requirements for the application of growing media. This superabsorbent hydrogel is made with citric acid as a cross-linking agent carried out by the cross-linking process.

2. Research Methodology

2.1. Materials

The materials used in this study include Polyvinyl Alcohol (PVA), Carboxymethyl Cellulose (CMC), Acrylic Acid, Citric Acid, Ammonium Persulfate, and Distilled water.

2.2. Procedures

1) Synthesis of Hydrogel Film

CMC is used as the main material in the manufacture of hydrogels. First, the CMC is heated in distilled water at a temperature of 60 °C and stirred using a magnetic stirrer for 30 minutes until homogeneous. The PVA is fed into the CMC solution, then heated to a temperature of 85 °C, and stirred until homogeneous. The composition of the ratio of the PVA content in hydrogel solutions is varied from 0%, 1%, 1.5%, 2%, and 2.5% (w/v). Next, 0.06 grams of Ammonium Persulfate is added to the polymer mixture and heated at a temperature of 60-70 °C to stir for 30 minutes. A total of 0.2 grams of acrylic acid is introduced into the mixture and then stirred until homogeneous. Next, 0.2 grams of citric acid as a crosslinker is added to the mixture and stirred for 30 minutes. A hydrogel mixture of 35 ml is poured into a petri dish, then dried in the oven to create a three-dimensional block shape at a temperature of 50 °C for 24 hours [7].

2) Characterization of the Superabsorbent Hydrogel Functional Group

The analysis was carried out using an FTIR spectrophotometer to determine the functional groups contained in the hydrogel structure. Measurements on the infrared spectrum were carried out in areas with a wavelength of 4000-400 cm^{-1} [7].

3) Gel Fraction Determination

Gel fraction analysis was carried out by soaking the hydrogel base at a temperature of 50 °C in distilled water for 24 hours, then dried in the oven at 40 °C for 24 hours to remove the water contained in the hydrogel. Many undissolved fractions indicate cross-links formed from hydrogels [8].

$$\text{Gel fraction (\%)} = (W1/Wo) \times 100\% \quad (1)$$

W1 = The weight of the dry hydrogel after soaking,

Wo = The weight of dry hydrogel (before soaking).

4) Swelling Ratio Determination

The swelling ratio is measured by soaking a hydrogel into the distilled water at room temperature. Gels that have absorbed water are weighed at certain times after removing the remaining water on their surface using filter paper. This continues to be done until there is no more weight gain [8].

$$\text{Swelling ratio (g/g)} = [(Ws-Wd)/(Wd)]x100\% \quad (2)$$

Ws = Weight of the hydrogel after swelling,

Wd = Weight of the dry hydrogel.

5) Determination of Mechanical Properties

Mechanical properties analysis was carried out using a universal instron testing instrument with a Tensile speed of 50 mm/min at room temperature. The hydrogel with the shape of a dumbbell is clamped at both ends with a special clamping device, and the engine is started in the on position, then there will be a withdrawal process at one of the clamp positions [9].

3. Results and Discussion

3.1. FTIR Analysis

The FTIR spectrum analysis in Figure 1 shows that the superabsorbent hydrogel has a typical peak in the absorption of wave number 3294.42 cm^{-1}, which indicates the presence of an OH group. The absorption that appears in the wave number 2924.09 cm^{-1} indicates the presence of a CH group. Then there is absorption that appears at the wave number 1415.75 cm^{-1}, indicating the vibration of the CH_2 functional group of the PVA. An uptake appears at the wavelength number 1303.88 cm^{-1}, a single bond group (C-C) that indicates a cross-linking process in the hydrogel. This follows previous studies [9], where the double bond (C=C) at the wave number 1617 cm^{-1} does not appear on all hydrogel spectrums. The double bond comes from acrylic acid, which has turned into a single bond (C-C) on the hydrogel spectrum.

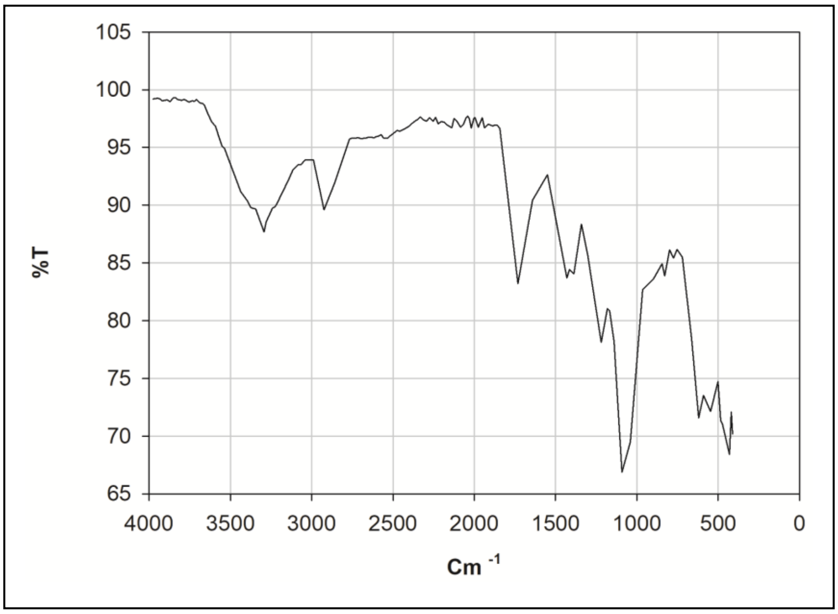

Fig. 1. FTIR spectrum of 2% PVA hydrogel after cross-linking.

3.2. Gel Fraction Analysis

Figure 2 shows that the percent of the gel fraction obtained decreases as the concentration of PVA in the hydrogel mixture increases. The hydrogel PVA 0% has a gel fraction percentage of 60.35%. Then there was a decrease in the gel fraction value in the PVA concentration hydrogel from 1% to 2.5%, with the gel fraction value of 57.26% dropping to 48.68%.

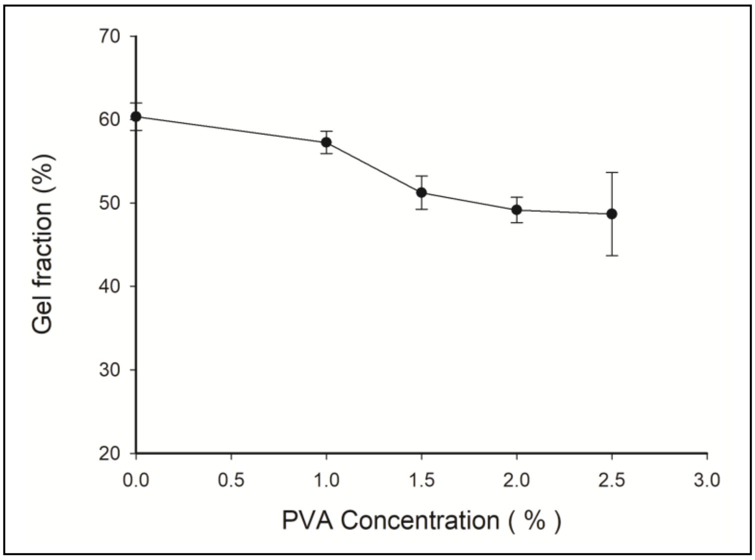

Fig. 2. The effect of PVA concentration on the gel fraction of the superabsorbent hydrogel CMC-Poly(Acrylic Acid)-PVA.

A decrease in the value of such gel fractions indicates that there are fewer and fewer crosslinkings formed. This is due to the formation of hydroxyl bonds in the hydroxyl group of the PVA [10]. The presence of hydroxyl groups contained in PVA can inhibit the occurrence of cross-linking. The higher the concentration of added PVA will cause the hydroxyl group to react more and more. This will result in the cross-linking being inhibited, so the gel fraction value will decrease. Based on the results of previous studies [11], hydrogels with gel fractions can be used for planting media applications between 50-60%. This shows that the hydrogel in this study that qualifies as a planting medium is a PVA concentration of 0%, which is 60.35% to a concentration of 1.5%, which is 51.24%.

3.3. Swelling Ratio

Based on Figure 3, it can be seen that there is an increase in the hydrogel PVA concentration of 0%-2.5%. The ratio of swelling hydrogel with PVA concentrations of 0% to 2.5% ranges from 719% to 895%. The swelling ratio value increases because the PVA has a hydrophilic group that triggers a synergistic effect with other polymer groups that form hydrogen bonds between molecular chains so that water molecules easily penetrate the hydrogel's pores [12]. The hydrophilic groups of other polymers that affect percent swelling are hydroxyl groups from cellulose [13] and carboxylic groups (COOH) of acrylic acid, which have a large affinity for water [14].

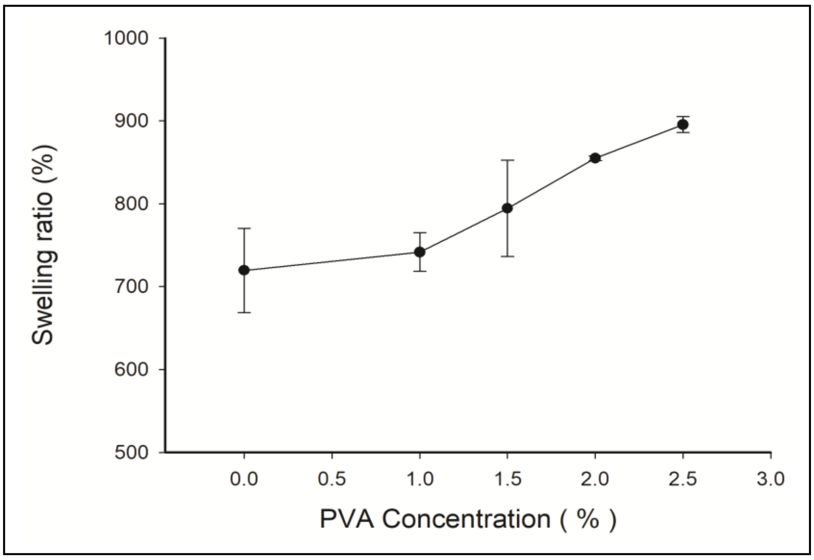

Fig. 3. The Effect of PVA Concentration on the Swelling Ratio of the Superabsorban Hydrogel CMC-Poly(Acrylic Acid)-PVA.

Based on previous research, the swelling value that can be used for planting media applications is between 300-600% [15]. In this study, a swelling ratio with a value range of 719.59-895.51% was obtained, so that this value met the requirements for superabsorbent hydrogels as a planting medium.

3.4. Mechanical Properties of Hydrogel

Figure 4 shows that the superabsorbent hydrogel's tensile strength value increases as the amount of PVA concentration in the hydrogel mixture increases. The tensile strength of the superabsorbent hydrogel CMC-Poly(Acrylic Acid)-PVA has increased at each concentration from 0% to 2.5%, with a strong tensile value from 0.365 – 2.165 MPa. Increasing in tensile strength value is due to the addition of PVA, which causes an increase in hydrogen interaction bonds between the unreacted OH group of the PVA and the carbonyl group of other components (the cross-link between acrylic acid and citric acid) in the hydrogel film. In addition, adding more PVA concentrations will cause the hydrogel matrix formed to be tighter so that the structure of the hydrogel produced is stronger.

Previous research on Biodegradable Hydrogel as a planting medium obtained a tensile strength value of 0.55-22.34 KPa [16]. In this study, the strong tensile value obtained has entered the range of these values so that the hydrogel formulation in this study can be applied as a planting medium.

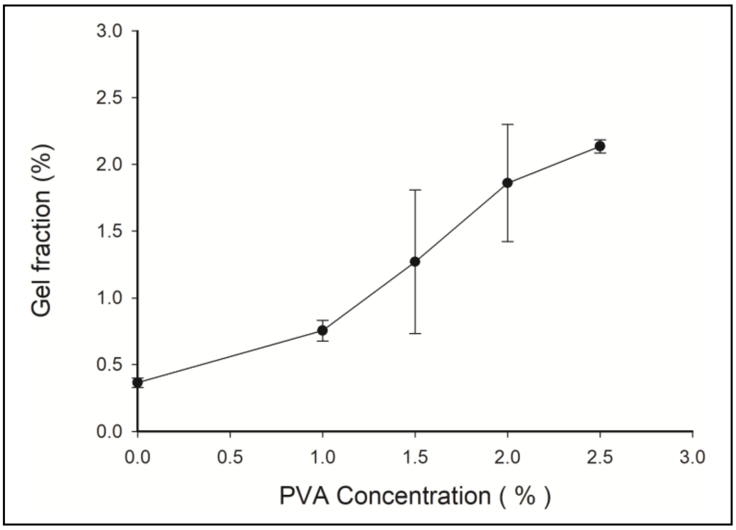

Fig. 4. The Effect of PVA Concentration on tensile strength of the Superabsorbent Hydrogel CMC-Poly(Acrylic Acid)-PVA.

The measurement of tensile strength is followed by the measurement of elongation, which is the maximum change that a material undergoes at the time of being pulled until it breaks.

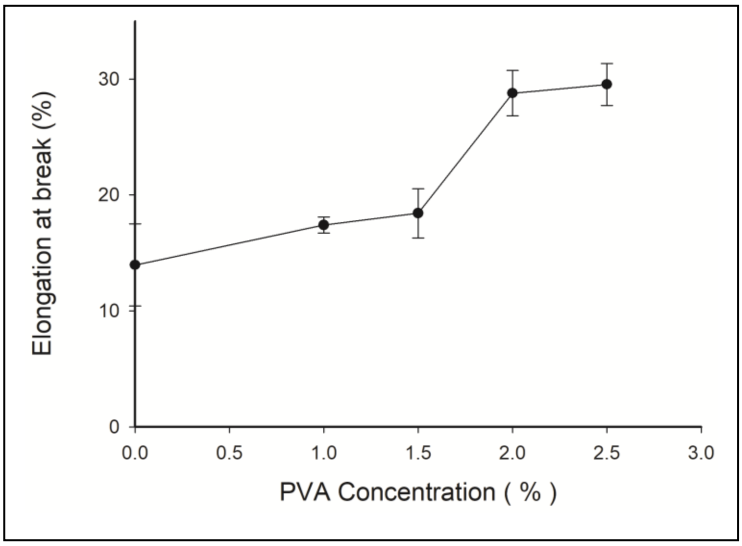

Fig. 5. The Effect of PVA Concentration on the Elongation of The Superabsorbent Hydrogel CMC-Poly(Acrylic Acid)-PVA.

From Figure 5, it can be seen that the addition of PVA concentrations will increase the percentage of elongation of the hydrogel. The elongation of superabsorbent hydrogels continues to increase at each concentration, namely at a PVA concentration of 0% - 2.5% having an elongation of 13.96%-30.82%. The increase in the elongation value is likely due to the addition of PVA which will increase the interaction bond between PVA and CMC and Acrylic Acid, which will cause the mobility of polymer chains to increase so that it will produce a hydrogel film that is more elastic and extensible or can be extended.

In a previous study on Cellulose-Based Superabsorbent Hydrogel as a Planting Medium, an elongation value of 3%-7% was obtained [17, 18]. In this study, the elongation value obtained has exceeded this value so that the hydrogel formulation in this study can be applied as a planting medium.

4. Conclusion

The degree of cross-binding of the CMC-Poly(Acrylic Acid)-PVA hydrogel decreases as the PVA increases. The value of the gel fraction obtained is 60.35% to 48.68%. The gel fraction level included in the range of requirements as a planting medium (above 50%) is at a PVA concentration of 0% to 1.5%. The swelling hydrogel ratio has increased with the increase in PVA concentration from 0.5% to 2.5%, ranging from 719% to 895%. This value has met planting media applications' requirements ranging from 300% to 600%. The mechanical properties of the hydrogel are in terms of tensile strength values and percent elongation. The tensile strength value obtained from this study was 0.365 MPa – 2.165 MPa. This value has increased with the increase in PVA levels and has met mechanical strong standards as a planting medium The percentage of elongation has also increased along with the addition of PVA, which is 13.96% to 30.82%.

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