Design and performance evaluation of edible film printing machine based on automatic casting knife

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Abstract. The development of edible films has been widely applied in recent years as an environmentally friendly food packaging, increasing shelf life and improving food quality. The most commonly used technique for producing starch-based films was classical casting, leading to film thickness measurement difficult. Therefore, this study aimed to design an edible film printing machine based on an automatic casting knife. The method used in this research was the engineering method. The edible printing machine was designed for a laboratory scale with a 1200 mm length, 500 mm width and 300 mm height. There were three main parts, namely an automatic casting knife, automatic pouring and control box. The performance evaluation showed that the automatic casting knife could be printing an edible film thickness between 0-20 mm with an accuracy level of 99.3%. An edible film with a length of 200 mm and 130 mm width can be printed in a shorter time (10 seconds). The edible film also has a smoother appearance on microscopic observation and was preferred by panellists to its appearance, texture and transparency parameters compared with edible film from manual casting. Based on the performance evaluation results that promise to be more efficient in printing edible film, this machine was expected to be scaled up and become a solution for the realization of Indonesian green packaging in the industrial revolution 4.0.

1. Introduction

The use of plastic cannot be separated from human activities [1]. With strong and valid reasons such as strong durability, flexibility, and low price causes the spread of plastic use around the world is very large. Based on data, it is estimated that plastic production will double in the next 20 years because the material that is often used in packaging and construction is not matched by competing materials [2]. Conventional plastic packaging is difficult to recycle, resulting in tons of plastic packaging being wasted in nature so that the waste problem increases every year [3]. Plastic pollution affects not only the land but also causes harm to marine and becomes an ocean pollutant. Plastic debris occurs on coastlines, in Arctic sea ice, at the sea surface, and on the seafloor [4]. In 2010, Indonesia was predicted to be the 2nd rank of top 20 countries by mass of mismanaged plastic waste, with 0.48–1.2 million metric tons Plastic marine debris per year [5].
Plastic debris is tough to remove from open ocean environments. It has been suggested that the most effective mitigation strategies are to reduce and substitute input/upstream (pre-consumption) plastic into biodegradable plastics (frequently derived from plant material) as an alternative to using plastics derived from petrochemicals [5, 6]. Biodegradable plastics are plastics that can be used like conventional plastics (non-biodegradable) but will be broken down by the activity of microorganisms. An extremely feasible alternative, both in terms of food safety and renewable resources, is the use of edible films or coatings [7]. Edible films, with a low environmental impact, have been progressively improved to protect various food products effectively.

However, the most widely used technique for the production of starch-based films is classical casting. These techniques lead to film thickness measurement difficulties since the mass of film-forming suspension controls it poured on a small plate (petri dish or glass plate) [8]. Hence, the tape-casting technique, known as spread casting or knife-coating, has been widely used in paper, plastic, ceramics and paint manufacturing industries [9]. By these methods, the film thickness is controlled from micrometric screws and the pouring film-forming solution was done manually. Therefore, this study aimed to design an edible film printing machine based on an automatic casting knife. This technology is an eco-friendly technology because it is environmentally friendly and does not endanger the surrounding environment and helps overcome environmental problems caused by plastic waste.

2. Material and Methods

2.1. Materials
The materials used for the manufacture of the machine such as 4mm acrylic glass, motor stepper (NEMA 1 17HS4401 and 17HS3430), power supply (LRS-150-24), microcontroller (ATmega 2560), mini liquid pump (385B-9), stainless steel, linear shaft rail, linear rail shaft support (SK8), bearings, leadscrew (T8), control box. While the materials used for edible film solutions are cornstarch, distilled water, CMC, glucose, glycerol, and tween80.

2.2. Methods
The method used in this research was the engineering method. The activities carried out include problem identification, designing process (manufacture and control system design), and performance test to modify.

2.3. Concept design
The edible printing machine was designed to be used for a small scale industry or laboratory scale, so it has dimensions 1200 mm in length, 500 mm of width and 300 mm in height. The machine consists of 3 main parts, namely an automatic casting knife, automatic poring and control box. Figure 1 shows the 2D and 3D design of the edible printing machine and its dimensions.

![Figure 1. 2D and 3D design of edible film printing machine.](image-url)
The thickness and plate speed was controlled by the microcontroller using stepper calculation:

- **Step value:**
  
  \[ \text{angle value} = \frac{\text{stepper angle}}{\text{divider}} \]  
  \[ \text{angle value} \times \frac{1}{\text{revolution or } 360˚} \]  
  \[ \text{step value} = \frac{\text{angle value}}{1 \text{ revolution or } 360˚} \]  
  \[ \text{steps} = \frac{\text{angle value}}{1 \text{ revolution or } 360˚} \] (2)

- **Leadscrew displacement:**
  
  \[ \text{lead screw distance} = \frac{\text{the distance (mm)}}{\text{step value}} \] (3)
  \[ \text{lead screw displacement} = \frac{1}{\text{lead screw distance}} \] (4)

Where the angle value is 1.8 degrees based on step angle datasheet of two stepper motor used. The value of leadscrew displacement is obtained by inversion of equation (3) since the leadscrew is rotated one revolution (step).

2.4. **Edible film preparation process**

Edible film solutions were prepared by dissolving 10 grams of corn starch and glycerol 3 mL into the distilled water. The suspension was continuously stirred at 80-90°C for 22 minutes. Furthermore, the suspension was cooled to a temperature of 45°C [10]. The casting process is divided into two methods: casting with a designed printing machine and classical casting. The casting process uses a designed printing machine, starting from the edible mixture's input into the glass chamber. Then turn on the power button and the machine will perform an altitude calibration since it was first turned on. The height of the casting knife which was adjustable according to the thickness of the edible film. Afterward, click start and the casting process lasts for approximately 10 seconds. At the same time, the manual casting process starting by pouring the edible mixture on top of the glass, which has given a height limit on all sides. Next, the mixture was flattened with a metal ruler. The drying process was carried out for both methods at ±50°C for 10 hours and subsequently cooled at room temperature for 24 hours.

2.5. **Performance test**

In this study, the performance testing on the printing machine and the edible output film. The casting knife thickness accuracy test was carried out by comparing the input value and the actual knife height. The edible films cast, both by printing machine and classical method, are subjected to microstructure testing by Scanning Electron Microscopy and organoleptic tests using a hedonic scale from 22 panelists.

3. Results and Discussion

3.1. **Design of edible film printing machine**
The edible printing machine was designed to be limited on a lab-scale to simplify the process of creating edible films used for research on edible films and casting other solutions such as membrane casting. The edible casting printing machine that has been made and its parts can be seen in Figure 2.

This machine consists of 3 main parts: the automatic casting knife, automatic pouring and control box, which will be explained in the next section. The power source needed by each component of this machine is the DC voltage, so an AC to DC converter and power supply is required to support the electric current to each component. This machine is also equipped with auto-calibration. When the power button is turned on, the acrylic plate, which is the glass plate base, will be in the initial position.

3.1.1. Automatic casting knife
The automatic casting knife was an important part of the casting process. The automatic casting knife was placed after the mechanical casting section. In this section, the material that has been poured will be cast or leveled using a stainless steel plate. The casting knife uses stainless steel as a material with a high chromium element, which causes its rust-resistant characteristics. The detailed automatic casting knife is shown in Figure 3.

![Figure 3. Detailed component of automatic casting knife.](image)

Besides, to support the automatic movement of the casting knife, there are several components used, such as stepper motor, bracket stepper motor, flexible coupling, T8 leadscREW, linear, smooth rod stainless rail, and two S8UU linear bearings. On this stepper motor, it is connected to the coded Arduino Mega so that by using the control box input can be made with a range of height values between 0 - 20 mm and the value will be shown on display on the control box.

3.1.2. Automatic pouring and plate
The automatic pourer consists of several constituent parts, namely an acrylic plate, mini liquid pump, and stainless steel frame as a support for the output hose edible forming solution, as shown in Figure 4. The plate was made from 4 mm acrylic that size of 210 mm in length and 150 mm in width. At the top of the acrylic, the plate was equipped with thin glass, which is a film basis and makes it easier to move the next step, the drying process. Simultaneously, the thin glass has a 200 mm of length and 130 mm of width and the extent of film size produced.

The pouring process will occur automatically after the plate is moved. Furthermore, the edible forming solution will be transported from the chamber to the top of the thin glass plate using a mini liquid pump with setting the pouring speed of 28 ml/s. The automatic pouring also controlled to stop when the acrylic plate has passed through the stainless steel frame. The hose was designed into two outlets so that the solution can be spread evenly throughout the plate section. The plate is also complemented by motor stepper, linear shaft rail smooth rod stainless, linear bearing, and T8 leadscREW. Based on equations (1-4), the plate speed was controlled and steady at 25 mm/s. With such speed, the total time required for casting with these machines is approximately 10 seconds.
The plate also includes a barrier on both sides of the thin glass plate. It has functions to enable the mold does not spread to all sides and ensure that no contaminants during the casting process. The borders are made of stainless steel.

3.1.3. Control box

The control box has the main function to regulate the machine operates automatically. The film thickness, pouring and casting speed are controlled by Arduino Mega 2560 R3 contained in the control box. The control box is equipped with an LCD display to show the input film thickness, pouring speed and plate speed. It also has a start printing, power on/off button and thickness set button. The recommended input voltage to be able to power the Arduino is around 7V to 12V. This is because if it is too low, Arduino works unstable and if it is too high, Arduino will heat easily and quickly experience damage.

3.2. Thickness accuracy

The thickness accuracy test aims to see the input's suitability on the LCD with the actual conditions. The actual condition is the response value or the casting knife's height after inputting the value into the control box. The thickness accuracy test result is shown in Figure 5.

Based on Figure 5, the comparison of the input value on the LCD and the actual value have a high correlation value of 99.3%. This regression value is close to 1, indicated that the automatic casting knife designed has worked well for printing an edible film with an accurate thickness. Furthermore, with high accuracy and varying material thickness (0-22 mm), this machine can also print other thin films like mixed-matrix membrane [11] and bioplastic [12].
3.3. Microstructural analysis
Scanning Electron Microscopy (SEM) testing was conducted to compare the visual appearance between machine-cast and manually-cast method. The SEM results for both edible films at magnifications of 300 times and 10,000 times are shown in Figure 6.

![SEM images](image)

**Figure 6.** Microscopic images of the edible film that processed with the classical casting at 300 times magnification (a) and 10,000 times magnification (b), and also with designed printing machine casting at 300 times magnification (c) and 10,000 times magnification (d).

Based on Figure 6, it can be seen that there is a significant difference in microscopic images between the casting process with the machine and the manual casting of the resulting edible film surface. The edible film’s surface treated using an automatic edible film printer is smoother when compared to manual treatment with a magnification of 300 times or 10,000 times. As shown in the picture, spheres such as air bubbles are also found on edible films painted manually. This is thought to be caused by the material which is not entirely gelatinized due to improper stirring, time, and drying temperature.

3.4. Organoleptic test
Since the output product from this machine was an edible film, the organoleptic test using a hedonic scale was carried out between edible film produced from the designed printing machine and manual casting against the texture, appearance, and transparency parameters shown in Figure 7.

![Hedonic scale](image)

**Figure 7.** Organoleptic parameters when compared with the manual casting.

Based on Figure 7, the panelist gave higher values to edible film samples with an edible film printing machine for all organoleptic parameters compared with manual casting. The average preference value of 6 indicates that the 22 panelists like or can accept the edible film produced using a printing machine.
4. Conclusions
Designing and performance evaluation of edible film printing machine based on automatic casting knife was carried out. The edible film printing machine was designed for a laboratory scale with a dimension L, W, H of 1200 mm, 500 mm, and 300 mm. The automatic casting knife could print an edible film thickness between 0-20 mm and 99.3% accuracy. An edible film with a length of 200 mm and a width of 130 mm can be printed quickly (10 seconds) with low energy needed. The machine-produced edible film also had a smoother appearance. It was preferred (with an average value above 6) by panelists to its appearance, texture and transparency parameters compared with edible film from manual casting. For further research, an integrated drying process is required in the machine to increase printing efficiency. However, based on the performance evaluation results, which promises to be more efficient in printing edible film, this machine was expected to be scaled up and become a solution for the realization of Indonesian green packaging in the industrial revolution 4.0.

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