The effect of adhesive type and speed pan granulator on the properties of urea slow release fertilizer

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Abstract. The application of slow-release fertilizer (SRF) to agriculture provides many benefits. Productivity increases and at the same time, negative impacts decrease. This type of slow-release matrix fertilizer offers an excellent solution for increasing nutrient uptake by plants and restoring agricultural land. The objectives of this research are to study the effect of the type of adhesive and the rotational speed of the granulator on the physical properties of urea slow-release fertilizer (USRF). There are four characteristics used as responses, namely; bulk density, water absorption, granules yield, and durability. The granulation process is carried out using a disc granulator. The study was conducted using one factor at a time method. Research has been carried out by varying the rotation speed of the granulator 5 to 25 with a range of 5 rotations per minute on five adhesives, namely; tapioca flour, glutinous rice flour, rice flour, sago flour, and corn flour. The results showed that the types of adhesives affect the values of bulk density, water absorption, granules yield, and durability. The best type of adhesive is tapioca, however, USRF tapioca adhesive has weakness on water absorbency. Increasing the rotational speed of the granulator causes an increase in the value of bulk density, water absorption, and granules yield while the endurance parameters decrease.

1. Introduction
Indonesia is an agricultural country which has around 15 million hectares \cite{1} of wetland agriculture and the fourth largest population in the world \cite{2}. The population of Indonesia reaches 256 million people \cite{3} and more than 60\% of Indonesia's population work in the agricultural sector. An exponential increase in annual population demands reliable food availability. Therefore, agriculture is a very important sector. In 2016, Indonesia has provided 30.1 trillion rupiah in fertilizer subsidies for 3 years in order to encourage food self-sufficiency and increase crop yields \cite{4}. Unfortunately, the production capacity of paddy’s is still in low level, around 5.1 tons/ha \cite{1}, only. One of the problems is the low efficiency of nitrogen uptake by plants. About 50-70 \% of urea fertilizer is lost and has a negative impact on health and the environment \cite{5}.

Fertilizer is a material that is added to the growing media that functions as a supplier of various elements needed by plants. The nutrient elements are classified into two, namely macro nutrients (N, P, K,
Ca, Mg, and S), and micro nutrients (Zn, Cu, Mo, Co, B, Mn, and Fe) [4]. Fertilizers are an input that is essential in the process of agricultural production [5]. Fertilizers can be classified into two based on the source of manufacture, namely organic and chemical fertilizers. Organic fertilizer is fertilizer that is partly or wholly derived from plant or animal parts [6]. Some examples of organic fertilizer are compost, livestock manure [7], bird manure, whereas chemical fertilizer is fertilizer made by humans from the processing of mineral materials [6]. Organic fertilizers are environmentally friendly, in addition to having an impact on increasing production synthetic or chemical fertilizers also have a negative impact on health and the environment [8].

Urea is one of the agrochemicals fertilizer which is the main source of nitrogen because it consists a high N nutrient. The level of its utilization by plants only ranges from 30 to 50 %, the rest is lost to the environment through several processes, such as ammonium volatility, alkylation, leaching, and nitrification [9, 10]. Furthermore, it also has detrimental effects in the economic aspect of the issue: material losses, spent energy and human work effort negatively affect the total economic balance of the whole agrochemical production process [5]. Prilled urea is easily solute in the water. Basically, the rate of nutrient release can be reduced by inhibiting the mass transfer process of urea from solid phase into a liquid phase [11]. One method used to overcome it is by modifying the physical form of prilled urea fertilizer into a new type of urea fertilizer that has slow or controlled solubility [12, 13].

There are many factors affects the granulation processes. Granulation needs adhesive to improve the physical properties of the granules, especially the compactness of the granules. The adhesive used as a mixture can be natural or synthetic adhesives. A good adhesive has excellent characteristics such as; good adhesion, not harm plants, be easily found, and be affordable. The second factor which influences granulation is the rotational speed of the pan granulator as it affects the interaction of the type of adhesive and the size of the granule. The theme of granulation research in making slow/controlled-release fertilizer is a concern of many researchers. Many people have researched on granulation with granulators [14-16]. Some factors of concern are the type of adhesive, adhesive concentration, rotation speed, the slope of pan, adhesive flow rate, and rotation time [15]. The response parameters observed were durability, bulk density, yield percentage [15, 16], mechanical stability [15], compressive strengths [17], time of dispersion and elemental concentrations of the granules [17, 18]. However, the literature on granulation matrix consisting of carbon, zeolite with adhesive natural polymer (starch) is very limited. Though the mixed matrix has the ability to form a slow release fertilizer at the same time to remediate agricultural land.

Based on the description above, it is necessary to conduct a study on the effect of adhesive type and the rotational speed of the granulator toward the physical properties of urea slow release granules. The adhesives are made from natural starch which contain a large percentage of amylopectin, easy to find and the price is relatively affordable. The matrix consists of zeolite, carbon with certain ratio and mixed with clay. This study also observes at the effect of the granulator speed. Through this study, it is expected to reveal how the influence of adhesive types and the rotation speed of the granulator affect the quality of urea granule fertilizer.

2. Method
The zeolite powder which has been activated by NaCl 10 grams is mixed with 60-gram carbon which has been modified with cetylpyridinium chloride (CPC). Surfactant modifications of carbon and zeolite activation were carried out by ultrasound model TU-250 Y voltage 220 V / 50 Hz power 250 W. The solid mixture is then put into a solution made from 20-gram Urea in 60 ml demineralised water. The concentrated suspension is stirred evenly and put in the oven for 3 hours. The solid is mashed and mixed with clay powder. The mixture is granulated at certain speeds (5 RPM, 10 RPM, 15 RPM, 20 RPM, and 25 RPM ) and spraying a certain type of liquid adhesive. There were five adhesive materials used in this
research, namely; tapioca flour, glutinous rice flour, rice flour, sago flour, and maize flour. The granulation process is carried out using a pan granulator. The granulator consists of a rotating pan with adjustable speed motor. The diameter of the pan is 46.5 cm and depth is 16 cm. The results obtained were sieved to get granules product yields. Products which met good quality standards are tested for other physical parameters, namely; bulk density, water absorption, and durability. The effect of factors to response was evaluated statistically by analysis of variance (ANOVA) single factor.

3. Results and discussion

3.1. Effect of adhesive types on the physical properties of SRF granules

There are three (3) forces work together on powder in a pan granulation process, namely frictional force, centrifugal force and gravitational force. The powder rise along with the revolving pan under frictional force, all down by gravitational force and moves to the pan edge because of centrifugal force. The powder rolls in a certain trace under the function of these three forces. The powder collides each other and or collide the pan edge during granulation. Liquid adhesive spray covers the powders and binds the closest neighbor which contact them and compact through the pressing by collision forces and forms nucleus of granules. After the nucleus of granules formed, the next process is growing them into critical size. Critical size is the maximum size of granules. The next collision with other breaks them into small or nucleus of granules. This process continue and gradually attains the certain size.

Figure 1 shows the effect of various adhesives on bulk density, yield granules, durability and water absorption. The type of adhesive as the x-axis is arranged based on the percentage of amylopectin content. Maize starch is on the left side and sticky rice is on the right side, while sticky rice, rice, sago are placed sequentially in the middle. Amylopectin content in cornstarch, sago, rice, tapioca and sticky rice are 70 %, 73 %, 80 %, 91 % and 99 %, respectively.

The largest bulk density value (0.8492 gr/ml) is the granule of tapioca adhesive while the smallest one (0.6659 gr/ml) is granules of maize adhesive as shown at Figure 1(a). Koukkanen (2013) stated that different chemical composition of complex carbohydrates (amylopectin) on flour will affect the bulk density of granules [19].

This study is in line also with Gaudin et al. [20]. He stated that starch with a high content of adhesive gives a high value of bulk density. It is indicated that the samples with more starch adhesive content have a large bulk density. In general, increasing amylopectin content in starch increases the value of bulk density.
density. However, the maximum condition does not happen on the starch with maximum amylopectin but tapioca starch adhesives. This happens because adhesives made from tapioca flour have better viscosity values than adhesives from other starches. Single factor ANOVA analysis carried out by putting the percentage of amylopectin on starch as x-axis and bulk density. The results of the single factor ANOVA analysis of the bulk density data obtained a P-value of 0.00015780.

**Yield of granules** is defined by the percentage of granular 2-5 mm size. The yield of granules is defined by the percentage of grain size of 2-5 mm. As seen in Figure 1(a), the pattern of increasing yield granules is similar to the pattern of increasing bulk density. The highest percentage of granular 2-5 mm size is produced by tapioca flour adhesive that is 98.35 %, and the lowest is from maize adhesive which is only 57.64 %. Tapioca flour has the ability to glue an ingredient because it contains a lot of starch which high content of amylopectin and good viscosity, so that during the granulation process liquid adhesive could be easily sprayed in small spray holes and granules will be easily formed due to the adhesion produced is quite well. The results of the single factor ANOVA analysis of the yield data obtained a P-value of 0.001335. This means that the type of adhesive effects yield of granules.

The effect of adhesive type on durability and water absorption is shown in Figure 1(b). The result of this research shows that the durability pattern similar to the pattern of yield and bulk density. The highest **durability** is produced by tapioca flour adhesive which is 99.87 % and the lowest is maize adhesive which is 96.09 %. On other research shows that tapioca adhesives are better than molasses [21]. The difference is caused by the chemical composition of each different adhesive. Flour chemical composition consists of complex carbohydrates (amylopectin) which are sticky, it can increase bonding between materials in fertilizer granules to increase resistance on pressure and friction that is received by granule fertilizer during carrying and transportation. Data analysis with single factor ANOVA obtained P-value of 0.00000220502.

Figure 1(b) describes the effect of adhesive type on percentage of water absorption. It can be seen that the highest percentage of water absorption is produced by adhesive made from maize, which is 52.48 % and the lowest is Tapioca adhesive type, which is 35.08 %. This is due to the fact that tapioca flour has the ability to glue an ingredient because it contains a lot of starch composed from two kinds of carbohydrates, namely amylase and amylopectin, so that during the granulation process granules will be easily formed due to the good enough adhesion strength produced [21]. This research is in accordance with previous studies which mentioned that there was a tendency that the addition of the adhesive types with good adhesion actually reduced water absorption [22]. Data analysis using single factor ANOVA obtained P-value of 0.00007801.

**SEM** (Scanning Electron Microscope) test shows that the morphology of granules are different. Figure 2 indicates that the granule with tapioca adhesive looks compact with small porosity, while granule with maize adhesive looks less compact with bigger porosity. Granule with tapioca adhesive looks smoother and flatter surface, slightly fractured, while granule with cornstarch appears to be uneven and consist of large number of fractures with large holes.
3.2. Effect of granulator rotation speed on the physical properties of SRF granules

In this study, the granulation process was carried out by varying speeds of 5, 10, 15, 20, 25 RPM on a disc granulator. The process was run out within 20 minutes with the same quantity of tapioca adhesive. The resulting granules are tested for their physical properties. Figure 3 describes the changing of physical properties on various speed rotation of pan granulator. The section (a) shows the effect of speed rotation on bulk density and yield granules, while section (b) illustrates the Effects of granulator speed on durability and water absorption.

Based on the Figure 3(a), it can be seen that the highest bulk density value is resulted at a rotation speed of 25 RPM that is 0.8149 and the lowest is at a speed of 5 RPM which is 0.696. This study is in line with Irshad et al. which showed that increasing speed rotation tends to increase bulk density [23]. Besides, the size of the granule also affects the density value. Smaller size of granule and its similarity will increase the density value because the smaller size will fill the space or gap between the particles so that the mass of the granule is greater than the larger granule [8]. Analysis of data using the single factor ANOVA, obtained P-value of 0.000489.

Figure 2. Morphology of granules with the different type of adhesive
Figure 3. Physical properties of granules SRF at various speed rotation granulator. (a). Effects on bulk density and yield granules; (b). Effects on durability and water absorption.

The percentage of 2-5 mm size granules also affected by speed rotation. Figure 3(a) shows that the percentage of granule in size of 2-5 increased with the increasing of speed rotation. The highest percentage of 2-5 mm size granule is produced by the rotation speed of the 25 rpm granulator that is 95.99 % and the lowest is the rotation speed of the 5 RPM granulator which is 83.89 %. This research is in accordance with other research which states that the average particle diameter increases by the increase up to 25 rpm from granulator pan [23]. In the analysis of data through single factor ANOVA, P-value of 0.00006866 was obtained.

Figure 3(b) illustrates durability and water absorption on various granulator rotational speed. The graph shows that durability decreased with the increase of speed rotation from 5 to 25 rpm. Variations in pan rotation speed effectively change the growth behavior of granulation, which includes not only changes in the granulation growth rate but also the interactions between the basic units that make up the final granulation [16].

The comparison of this study with some standard granules is represented in Table 1. All granule parameters in this study settle within the standard range. It indicates that the range value of factors of this research could achieve good quality of granules.

Table 1. Comparison of test results with quality standards

| Parameter                        | Quality Standard                                      | Results               |
|----------------------------------|-------------------------------------------------------|-----------------------|
| **Bulk Density**                 | The greater the starch content (amylopectin) in the adhesive, the more bulk density will increase [20]. | Tapioca (amylopectin 91%) = 0.8492 gr.cm$^{-3}$. Maize (amylopectin 70%) = 0.6659 gr.cm$^{-3}$ |
| The percentage of Granule 2-5 mm Size | Min 80% [24]                                         | 57% - 98%             |
| Durability                       | pellet *non wood* ≤ 96% [25]                          | 96% - 99%             |
| Water Absorption                 | pellets or granules generally range from 20% - 60% [26] | 35% - 52%             |
4. Conclusion
The results of this study indicate that the type of adhesive (tapioca, sticky rice, rice, sago, and corn) affects bulk density, water absorption, granules yield, and durability. Figures 1.a and 1.b show that tapioca adhesives provide granules with three physical properties better than others. Bulk density, yield of granules and durability show the best position, which is the highest value compared to others. While the physical property of water absorbency is in the lowest position. Granules fertilizer should posses a high capacity of water absorbency. Considering experimentally obtained results, it was observed that tapioca adhesive gave more beneficial physical properties compared to others. The results also show that the increasing speed of the granulator rotation causes an increase of three responses, namely; bulk density, water absorption, granules yield; but decreases granule’s durability. Based on the data in Table 1, it can be concluded that the granules which were produced in this study meet the standards quality. Moreover, research can be improved by optimizing 2 (two) or more combinations of factors to find the value of the factors that produce the best granule properties.

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