# Potentials of Edible Canna (*Canna edulis* Kerr) Starch for Bioplastic: A Review

# *Potensi Pati Umbi Ganyong (Canna edulis Kerr) sebagai Bahan Baku Bioplastik: Kajian Literatur*

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**Abstract**

Starch-based bioplastic was more economical and competitive compared to bacteria-based bioplastics (polylactic acid, polybutylene succinate, and polyhydroxyalkanoates) due to the starch variances and the availability in Indonesia, along with the simple techniques that can be applied. This review aimed to describe the potential and opportunities of edible canna starch as an alternative raw material of bioplastics production. Edible canna tuber productivity in Java, Indonesia, with a harvest age of about eight months reaches 30-49.4 tons/ha. It will produce a mature segment 70.2% of the total harvest weight. Edible canna tuber was a carbohydrate source that contains 88.10% starch with an advantage of 68% higher fiber and mineral content than other tubers. Furthermore, canna tuber starch contains amylose proportions of 35.0%. The high amylose content in canna starch is one of the properties that can position its function for developing packaging materials. The gelatinization process of canna starch requires a short time and low energy because of its large granule size (56 μm). A literature review of canna starch as an alternative of bioplastic raw materials needs to be carried out to obtain accurate data and information regarding treatment, use of additional materials, and characteristics of bioplastic products resulting from experimental studies so that they can be further implemented.
**Keywords:** bioplastics, edible canna, starch

***Abstrak***

*Penggunaan pati sebagai salah satu bahan utama produksi bioplastik bernilai lebih ekonomis dan kompetitif dibandingkan dengan bioplastik berbasis bakteri (polylactic acid, polybutylene succinate, dan polyhydroxyalka-noates) karena variasi dan jumlahnya yang melimpah di Indonesia dan teknologi sederhana yang dapat diaplikasikan. Tujuan kajian literatur ini adalah untuk menggambarkan potensi dan peluang pati ganyong sebagai alternatif bahan baku pembuatan bioplastik. Produktivitas umbi ganyong di Pulau Jawa dengan umur panen sekitar 8 bulan mencapai 30-49,4 ton/ha. Ganyong merupakan sumber karbohidrat yang mengandung 88,10% pati dengan keunggulan berupa 68% kandungan serat dan mineral pada pati yang lebih tinggi dibanding umbi-umbian lain. Pati umbi ganyong juga mengandung amilosa sebanyak 35,0%. Kandungan amilosa yang tinggi pada pati ganyong merupakan salah satu sifat yang berfungsi dalam pengembangan bahan pengemas. Proses gelatinisasi pati ganyong membutuhkan waktu yang sebentar dan energi yang rendah karena ukuran granulnya yang besar (56 m). Kajian pustaka pati ganyong sebagai alternatif bahan baku bioplastik perlu dilakukan untuk mendapatkan keakuratan data dan informasi mengenai perlakuan, penggunaan bahan tambahan, dan karakteristik produk bioplastik yang dihasilkan dari kajian eksperimen agar dapat diimplementasikan lebih lanjut.*
*Kata kunci: bioplastik, ganyong, pati*

## INTRODUCTION

Conventional plastics have high demand and usage for primary, secondary, and even tertiary packaging in daily human life. The use of conventional plastics increases with the increasing urgen-cy of plastic materials in everyday life due to being lighter and easier to shape according to the desired design and size. These characteristics are not shared by other types of packaging, such as glass or metal. The continuous use of conventional plastics is detrimental due to their complex nature

to decompose naturally, increasing pollution and environmental damage (Kuruppalil, 2011; Santiago et al., 2015).

Various ways have been made to reduce plastics, including reusing, reducing, and recycling. Research on bioplastics is evolving to overcome the use of conventional plastics, given their biodegradable nature, and can fertilize the soil when returned to nature. Bioplastics decompose faster because they utilize natural polymers such as fats, cellulose, polylactic acid (PLA), and starch. (Malathi et al., 2014; Imran et al., 2014; Jabeen et al., 2015; Susanti et al., 2015). However, bioplastics have a low resistance to mechanical strength and are naturally hydrophilic (Kumar and Thakur, 2017).

Starch is a material that can be used in the production of bioplastics. Starch is obtained by extracting vegetal material that contains carbohydrates, such as cereals and various tubers. Sources of carbohydrates that contain lots of starch include sago, corn, cassava, rice, sorghum, sweet potatoes, canna, taro, and arrowroot. The unique functional characteristics of starch allow it to be applied to various purposes, such as food and non-food additives (Koswara, 2009; Kamsiati et al., 2017). According to Jabeen et al. (2015), starch-based bioplastics have the most significant demand than other types. Starch is more competitive, economical, and sustainable than petroleum since it is based on renewable materials. The process of bioplastics production from starch is simpler than other raw materials, such as bioplastics-based production involving bacteria (polylactic acid (PLA), polybutylene succinate (PBS), and polyhydroxyalkanoates (PHA)). The use of starch is flexible enough to be developed with various methods of making bioplastics. Cassava and corn starch are widely used in the production of bioplastics, which conflicts with food interests (Sriroth et al., 2001; Lu et al., 2009).

The abundant availability of starch in Indonesia makes it one of the preferred materials for producing bioplastics (Gadhave et al., 2018). *Porang* (*Amorphophallus mueller*) tubers, durian seed, and cassava peel starch (Harsojuwono et al., 2019; Thulasisingh et al., 2021; Khalil et al., 2018) are often used as biodegradable plastic raw materials. However, sago, sorghum, and edible canna starch (Imran et al., 2014; Santiago et al., 2015) are still rarely used. So far, starch-based bioplastics have been quite developed, considering the immense potential of natural resources explored in Indonesia. However, the selection of various types of starch developed and used as bioplastic materials to date is not sufficient to conclude on which type of starch is the best, considering the quality of both the mechanical and chemical characteristics of the bioplastics produced is quite varied.

Edible canna (*Canna edulis* Kerr) is easy to grow and does not have any particular pests and diseases. Edible canna thrives in areas with low nutrition and can grow throughout the year. Besides growing in low-nutrient areas, edible canna can also grow without irrigation on marginal soils or sloping land (Damayanti et al., 2017). The harvest period for edible canna is between 8-12 months (Hasanah & Hasrini, 2018; Utami & Diyono, 2011). In general, edible canna is used as an ingredient for consumption and even as animal feed. Figure 1 shows the appearance of edible canna.

Edible canna starch is starting to be applied as an industrial commodity dominate by food sector users. Some of its uses include making cookies, *cendol*, noodles, and edible coatings (Anggarini et al., 2016). The edible canna utilization is based on the starch characteristics, which has a higher amylose content of starch. The presence of high amylose in starch contributes to the bioplastic's tensile strength. The linear structure of amylose makes it easier to bind with other amylose molecules through hydrogen bonds than amylopectin (Maryanti et al., 2016).

This review aimed to describe the potential and opportunities for canna commodity as an alternative source of starch as a bioplastic raw material which can then be studied further as biodegradable packaging material. This knowledge is notable, since it can help head the future research and perfection of starch-based biodegradable plastic, particularly from tuber-based plant as a local wisdom abundant in Indonesia.



**Figure 1.** Edible Canna Tubers (*Canna edulis* Kerr.) (Witthayanant, 2000)

## DISCUSSION

### Edible Canna Tuber Potential

In Indonesia, there are two cultivars of edible canna, specifically red and white edible canna. Red edible canna can be identified by the purpleish or reddish stems, leaves, and midribs, while the white edible canna is identified by its green stems, leaves, midribs, and brownish rhizome scales. Compared to white edible canna, red edible canna has bigger stems, is mildly light-resistant and drought-resistant, and is challenging to produce seeds. The yield of wet rhizomes is more prominent but has a low starch content. Red canna rhizome is usually eaten fresh or boiled. White canna is smaller and shorter, less resistant to light but drought-tolerant, produces seeds, and propagated into plant saplings. The yield of wet rhizomes is smaller with a high starch content and is commonly used as a starch source (Imai, 2008).

In the process of growth, edible canna has only one main segment. The main sections grow into new segments within two months after the planting process. The new segment that grows and develops in the stem cell (main segment) is called the mature segment. Mature internodes can grow new internodes when the third month of planting is called the premature segment. The development and further growth of premature segments produce immature segments. The immature segments produce edible canna stems with 5 inches height. These sections will develop into mature segments (Vankar & Srivastava, 2018). Edible canna can be harvested after the seventh month of planting, ready to be harvested when they reach several physical characteristics as follow, (1) yellowish skin color, (2) the ends of each internode are covered with purple scales, and (3) have five or six generation internodes. The average weight and total weight of edible canna starch per tuber are described in Table 1.

Based on Table 1, an average rhizome consists of 52 segments. The immature segment is the most compared to other sections (56.5%). This immature segment indicate that the rhizome is still developing and can still produce canna tubers (Puncha-arnon et al., 2007). The mature segment average weight is the highest compared to the other segment. This high weight is due to the presence of starch in the mature segment. The lowest segment weight of 0.8% is the main segment, because several main segments are fibers derived from complex starch. The lowest starch content (3.5 grams) was found in the main segment. This low starch content indicates that the main segment continuously uses starch to energize the rhizomes when there is a lack of water and new internodes' growth after two months of planting.

With the morphological characteristics of the segmented tubers, it is beneficial for farmers to provide canna tuber material in a sustainably manner in meeting the needs of canna starch for various needs, one of which is the development of bioplastics. In addition, applying the main segment for producing new bulbs is more efficient than growing a new plant from seeds. In these ways, we could maintain the strain of plants and improve the quality of the tuber's origin.

The starch in edible canna is 88.10%, with an amylopectin content of 53.11% and an amylose content of 35% (Aprianita et al., 2014). The temperature around the planting location also affects the amylose content produced; the higher the temperature, the lower the amylose content (Matsue et al., 2002). Edible canna starch has a higher amylose content than sweet potato, cassava, taro, and potato starch (Hung & Morita, 2008). The optimal starch content is obtained when the harvest period is more than 12 months. Based on edible canna characteristics, they are identical to sweet potato starch content of 87.10%, with amylose content of 15.9%, and amylopectin content of 71.2%.

**Table 1.** Edible canna characteristics based on the segment classification (Puncha-arnon et al., 2007)

| Attribute | Immature Segment | Premature Segment | Mature Segment | Main Segment |
|---|---|---|---|---|
| Average number of segments per plant (segments/%) | 29 / 56.5 | 8 / 14.6 | 14 / 27.0 | 1 / 1.9 |
| Average weight of segments per plant (g/%) | 746.9 / 14.0 | 796.9 / 15.0 | 3,735.2 / 70.2 | 44.7 / 0.8 |
| Total starch per plant (g) | 102.3 | 1,155.4 | 694.7 | 3.5 |
| Moisture content (% based on wet weight) | 74.5 | 71.5 | 71.4 | 82.6 |

Indonesian Ministry of Health stated that edible canna tubers have 68% fiber and mineral content in starch higher than other tubers (Departemen Kesehatan Republik Indonesia, 1992). This plant's production is highly dependent on plant care, soil type, and other production factors. In Java, Indonesia, edible canna tubers' productivity is around 30 tons/ha, with the potential to reach 44.5-49.40 tons/ha at the age of eight-month-old of harvest. This plant is cultivated regularly in Central Java (Klaten, Wonosobo, and Purworejo Regency) and East Java (Malang and Pasuruan Regency). Indonesian Directorate General of Food Plants stated that edible canna is one of the prioritized root crops to be developed. Its production continuously increased in support of food diversification (Direktorat Jenderal Tanaman Pangan, 2017).

Based on its plant morphological properties and productivity, it is shown that edible canna has a massive potential to be industrial commodities. It could be an alternative starch-based commodity, both for use as food and non-food raw material. Nevertheless, with the emergence of starch product alternatives, it is better to determine the boundary on the use of commodities used to fulfill food and non-food needs due to conflict of interest between sectors.

**Characteristics of Starch Tubers**

Starch from plants comprises two types of different carbohydrates compositions, called amylose and amylopectin. Amylose is a straight-chain polysaccharide, part of the starch granules consisting of α-1,4 glycoside glucose molecules. Amylopectin is a branched polysaccharide, part of the starch grains (granules) consisting of glucose molecules bound to each other through α-1,4 glycoside bonds and branching through α-1,6 glycosidic bonds.

Amylopectin has a larger constituent monomer than amylose, so amylopectin forms a larger polymer than amylose. The ratio of amylose and amylopectin affects the starch paste's ability to form a gel or thickening of the paste. The intermolecular hydrogen bonds that form the starch play a role in determining the gel or film's cohesiveness. The linear structure of amylose makes it easier to bind with other amylose molecules through hydrogen bonds than amylopectin. Therefore, the strength of the gel or starch is determined mainly by the amylose content. The higher the amylose content, the greater the ability to form a gel and film layer. In contrast, amylopectin with a large and branched structure forms relatively weak hydrogen bonds.

The amylose and amylopectin content affects starch physicochemical properties, including water absorption, solubility, degree of starch gelatinization, and swelling power. Starch with high amylose content tends to absorb more water, is drier, and is less sticky (Jading et al., 2011; Koswara, 2009). Meanwhile, the higher the amylopectin content in starch tends to absorb less water, is wetter and stickier. The higher the amylopectin content, the easier it is to form the gel because of the lower gelatinization temperature. Gelatinization is a swelling process of starch granules due to heat and water, which evolved the granules' inability to return to their original shape (Sara et al., 2018).

Table 2 shows that the starch in several types of tubers contains different levels of amylose and amylopectin. The composition of amylopectin as a starch constituent ranges from 70 - 85%, and the amylose composition ranges from 15 - 30% (Sara et al., 2018). The tubers starch proportion is greatly affected on different cultivars and varieties in severally plant. Planting treatments and conditions also influence the proportion of amylose and amylopectin in various types of tubers (Noda et al., 2002). Edible canna starch has the greater amylose content among other types of tuber's starch, reaching 35.0%. The high amylose content on edible canna starch shows great opportunities use as an alternatives of bioplastic materials.

**Table 2.** Types of starch and its constituent components (Aprianita et al., 2014)

| Starch Type | Starch content (%) | Amylose (%) | Amylopectin (%) |
|---|---|---|---|
| Sweet potato | 87.1 | 15.9 | 71.2 |
| Taro | 75.4 | 10.1 | 65.2 |
| Cassava | 85.5 | 14.6 | 70.1 |
| Yam | 82.1 | 23.7 | 58.4 |
| Canna | 88.1 | 35.0 | 53.0 |
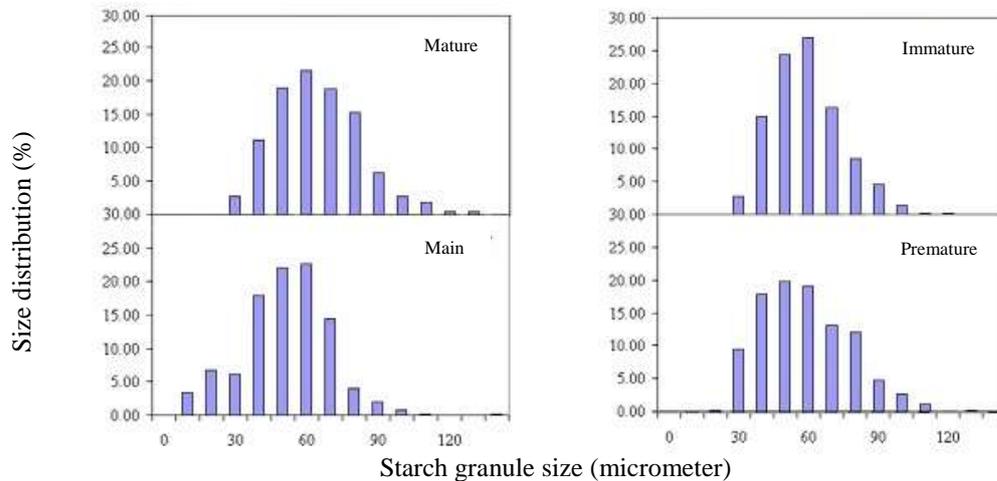
**Figure 2.** Characteristics of Edible Canna Starch Based on Harvest Period (Puncha-arnon et al., 2007)



(a)　　　　　　　　　　(b)　　　　　　　　　　(c)
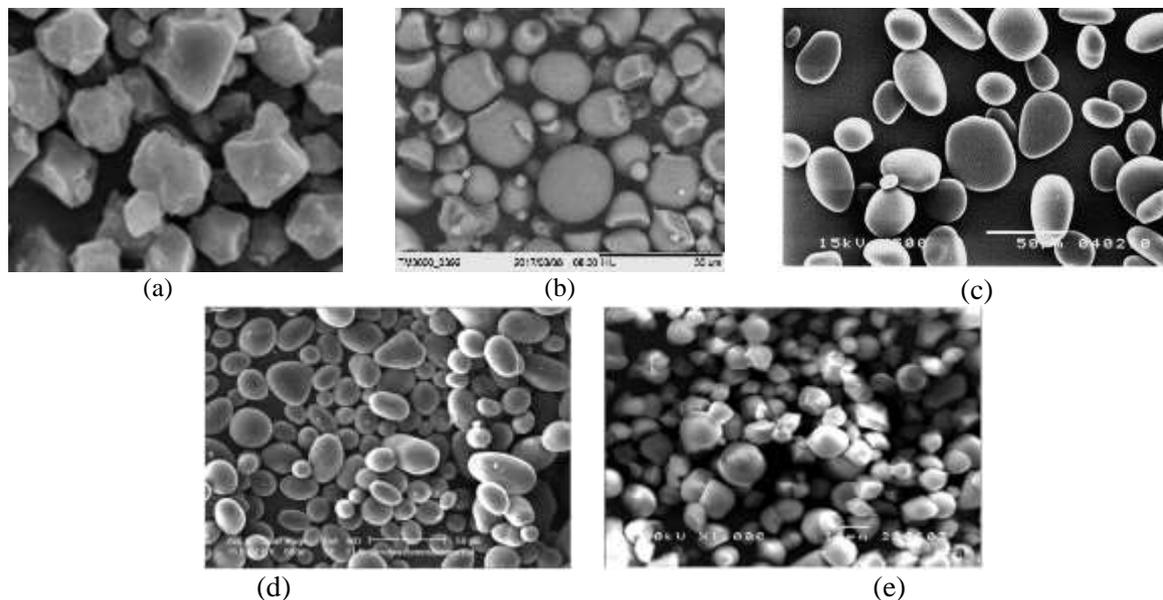
(d)　　　　　　　　　　(e)

**Figure 3.** Scanning Electron Micrographs of (a) Taro Starch (5000x) (Suhery, Anggraini, & Endri, 2015), (b) Cassava Starch (1000x) (Widyatmoko, Subagio, & Nurhayati, 2018), (c) Mature Edible Canna (500x) (Puncha-arnon et al., 2007), (d) Potatoes (500x) (Szymońska, Targosz-Korecka, & Krok, 2009), (e) Sweet Potato (1000x) (Ginting et al., 2005)

The difference in starch content can be affected by the level of purity in the starch extraction process. The more impurities present in the starch powder, the lower the starch content per unit mass. Some of the impurities commonly found in starch include fiber, sand, dirt, and other substances, identified as non-starch compounds. Starch content is also influenced by the optimum harvest age of starch source material. The faster the plants are harvested from the optimum harvest age, the lower the starch concentration produced. Harvest age on tubers can affect the level of starch produced. When harvesting is done at the right

time, the ingredients will contain optimum starch and little sugar content. The starch content in tubers harvested during the rainy season has a relatively lower starch content due to its high water content (Asgar et al., 2011).

Figure 2 shows that the characteristics of canna starch granules are very dependent on the tubers' harvest time. The size of canna starch granules at each harvest age ranges from 15 - 20%. Granule sizes range from 10 micrometers to 140 micrometers. Starches from the immature, premature, mature, and main segments show almost the same granule size, with a peak point in the size of

50-60 micrometers. However, a slight shift in the proportion of canna starch granule size shows a larger size when immature to early development. The average size of starch granules from immature, premature, and mature segments was 54, 53, and 60 micrometers. On the other hand, there are differences in granule distribution patterns that occur in the main segment. The starch granules' size in the main segment tends to be smaller, an average of 46 micrometers. Compared to the other segments, the granule size of the main segment is much smaller. This size difference is due to the starch composition in the main segment that has turned into fiber (Puncha-arnon et al., 2007).

The starch granules size ranges from 1 micron to 150 microns, related to the gelatinization temperature. Figure 3 shows the scanning electron micrographs of taro, cassava, mature edible canna, potatoes, and sweet potato starch. Table 3 shows that the smallest starch granule size is found in taro starch with a granule size of 2 microns with a relatively high gelatinization temperature of 75.4 - 80.2 °C. Large sizes starches granule tends to have a low gelatinization temperature due to their weak, molecular bonds. Thus that the energy required for the process is low. Whereas small-sizes starch granule tends to have high gelatinization temperatures due to their strong molecular bonds high energy are required for the process (Jading et al., 2011; Koswara, 2009). Gelatinization is when pure starch is heated in water; starch grains will expand so that the hydrogen bonds in the amorphous unit will be damaged and, will break at a specific temperature (Jabeen et al., 2015). By choosing canna starch from a mature segment, starch granules with a more homogeneous size will be obtained. Thus, the gelatinization temperature will be more stable with lower processing energy.

Gelatinization temperature is when the starch granule phase transitions from a regular to an irregular state. The temperature of starch gelatinization is influenced by the type of plant, moisture content, pH, sugar, fat, degree of cross-linking of amylopectin, the number of damaged starch grains, and the technology used (Jabeen et al., 2015). Some things that need to be considered in the starch gelatinization process are the composition of the water. If the dissolved starch solution is concentrated, the starch particles will be deposited (Ai & Jane, 2015).

**Canna Starch Potential as a Bioplastic Raw Material**

Bioplastics are obtained from biopolymers formed in the biological systems of organisms, especially plants such as starch, lignin, and cellulose. Biopolymers have biodegradability properties that allow biopolymer-based products to degrade naturally. In recent years, the use of bioplastics increased to 2.11 Mt per year in 2019 and is expected to be increasing to reach 2.4 Mt per year by 2024 (European Bioplastics, 2021). It should be noted that bioplastics must be distinguished from synthetic bio-based plastics made from monomers derived from biological systems and bio-based polymers are not always biodegradable. The utilization of edible canna starch, both in the form of natural and modified biopolymers, should be analyzed and studied further to identify whether they show appropriate behavior when they end up in the environment.

As a potential alternative bioplastic material, Canna starch has a granule size of 56 micrometers with a relatively low gelatinization temperature of 69.8 - 77 °C. This granule's size is the biggest compared to others. The size of canna starch granules is influenced by the harvest period's length, which is 8-12 months. According to Puncha-arnon et al. (2007), the granules' size was influenced by the length of the harvest period for the tubers. The longer the harvest time, the bigger the starch granules size.

**Table 3. Gelatinization temperature characteristics of several types of tuber starch**

| Starch Type | Granule Size (μm) | Gelatinization Temperature (°C) | | | | ΔH (J/g) |
|---|---|---|---|---|---|---|
| | | To | Tp | Tc | ΔT | |
| Sweet potato | 10 | 61.4 | 69.4 | 76.6 | 15.2 | 7.7 |
| Cassava | 15 | 61.1 | 68.2 | 74.2 | 13.1 | 8.1 |
| Taro | 2 | 69.7 | 75.4 | 80.2 | 10.5 | 7.6 |
| Potato | 19 | 62.9 | 73.5 | 80.5 | 17.6 | 11.3 |
| Canna | 56 | 64.1 | 69.8 | 77.5 | 13.4 | 11.4 |

Source: Puncha-arnon et al. (2007); Szymońska et al. (2009); Sit et al. (2015), Suhery et al. (2015); Maryanti et al. (2016); Widyatmoko et al. (2018).

Gelatinization temperature is when the starch granules experience structural damage until the retrogradation process occurs (Ginting et al., 2005). Gelatinization temperature was measured based on the definite viscosity increase of starch in the heating process using an amylograph. In Table 3, the initial temperature of cassava starch shows the lowest value (61.1 °C), and taro starch shows the highest initial gelatinization temperature value (69.7 °C). The initial temperature of gelatinization is a complex physical characteristic phenomenon of starch regulated by several factors, including the size of the starch granules and the heating medium's condition (Maryanti et al., 2016).

The amylose content also influences the gelatinization temperature in starch. According to Kearsley & Dziedzic (1995), the increase of gelatinization temperature is not only influenced by the starch granules sizes but also by the amylose content. The higher the amylose content and the starch granule size, the higher the gelatinization temperature. Judging from the size characteristics of edible canna starch granule (56 micrometers), the gelatinization temperature of edible canna starch is not much different from the gelatinization temperature of cassava starch (granule size of 15 micrometers). When viewed from amylose content, edible canna starch has the highest amylose content (35%) than other tubers. According to Maryanti et al. (2016), the imbalance of granule size and amylose content on gelatinization temperature assumes that the effect of a high amylose ratio on edible canna starch is more dominant on the increase in gelatinization temperature than the effect of starch granule size. In starch gelatinization, the enthalpy value is the energy requirements of starch during the gelatinization process due to the breakdown of the molecular structure (Nadia et al., 2013).

The use of starch in the production of bioplastics has a significant effect on physical quality in tensile strength, elongation rate, water vapor permeability, and biodegradability. Starch from tubers is a raw material that is often used in the manufacture of bioplastics. Because the starch from tubers has a high enough starch content and a low gelatinization temperature, this can reduce cost efficiency and energy use in bioplastics production. Edible canna starch as one of local wisdom should take a serious place for Indonesian bioplastic development. It could give more alternative materials utilized as bioplastic raw material to avoid the conflict of interest between food and non-food sectors.

The similarity of edible canna starch characteristics with several types of starch from other root sources indicates the potential for substituting identical bioplastic raw materials. Those characteristics are strengthened by the gelatinization value and starch content confirmed by the prerequisites required as a bioplastic material. This potential certainly needs to be studied further to obtain data accuracy and information regarding treatment, use of additional materials, and the characteristics of bioplastic products produced through experimental studies.

Besides, the development of starch-based bioplastic products, especially edible canna, needs to be a serious concern for various parties, given the urgency of solving the conventional plastics problems globally. Indonesia has a great opportunity to produce starch-based bioplastic materials considering the potential of mega biodiversity it has. Of course, with strategic steps in the form of readiness for appropriate technology and the scale of development, that should not only stop at the laboratory experiment level but increase at the pilot project level. These are things that need to be realized immediately to accelerate the commercialization process of bioplastic products. However, government policy support and changes in public and industrial consumption patterns for bioplastic products, which are still very limited, remain the main criteria for developing starch-based bioplastic products in the future.

## CONCLUSIONS

The result of the literature review concludes that the starch content of a material affects the quality of the bioplastic produced. The higher the starch content will increase the intermolecular strength in the bioplastic. The high productivity of canna tubers provides the potential availability of material for sustainable bioplastic production. Selection of canna with the right harvest time will affect the quality and quantity of canna starch produced. Canna starch has characteristics that are identical to other tuber starches, so that the starch has the potential to be a bioplastic raw material.

## ACKNOWLEDGEMENTS

## References

Ai, Y., & Jane, J. (2015). Gelatinization and rheological properties of starch. *Starch - Stärke*, *67*(3–4), 213–224. https://doi.org/10.1002/star.201400201

Anggarini, D., Hidayat, N., & Mulyadi, A. F. (2016). Pemanfaatan pati ganyong sebagai bahan baku edible coating dan aplikasinya pada penyimpanan buah apel anna (*Malus sylvestris*) (Kajian konsentrasi pati ganyong dan gliserol). *Industria: Jurnal Teknologi Dan Manajemen Agroindustri*, *5*(1), 1–8. https://doi.org/10.21776/ub.industria.2016.005.01.1

Aprianita, A., Vasiljevic, T., Bannikova, A., & Kasapis, S. (2014). Physicochemical properties of flours and starches derived from traditional Indonesian tubers and roots. *Journal of Food Science and Technology*, *51*(12), 3669–3679. https://doi.org/10.1007/s13197-012-0915-5

Asgar, A., Kusmana, Rahayu, S. T., & Sofiari, E. (2011). Uji kualitas umbi beberapa klon kentang untuk keripik. *Jurnal Hortikultura*, *21*(1), 51–59. https://doi.org/10.21082/jhort.v21n1.2011.p51-59

Damayanti, E., Poeloengasih, C. D., & Warakasih, I. (2017). Komposisi nutrien dan kandungan senyawa bioaktif pati ganyong (*Canna edulis* Ker.) kultivar lokal Gunungkidul. In *Prosiding Seminar Pemberdayaan Masyarakat Melalui Pemanfaatan Bahan Baku Lokal*. Gunungkidul: LIPI dan Pemerintah Kabupaten Gunungkidul.

Departemen Kesehatan Republik Indonesia. (1992). *Daftar Komposisi Bahan Makanan*. Jakarta: Bhratara Karya Aksara.

Direktorat Jenderal Tanaman Pangan. (2017). *Petunjuk Teknis Pengelolaan Produksi Aneka Kacang dan Umbi Tahun 2017*. Jakarta: Kementerian Pertanian.

European Bioplastics. (2021). *Frequently Asked Questions on Bioplastics*. Berlin: EUPB.

Gadhave, R. V., Das, A., Mahanwar, P. A., & Gadekar, P. T. (2018). Starch based bio-plastics: The future of sustainable packaging. *Open Journal of Polymer Chemistry*, *8*(2), 21–33. https://doi.org/10.4236/ojpchem.2018.82003

Ginting, E., Widodo, Y., Rahayuningsih, S. A., &

Jusuf, M. (2005). Karakteristik pati beberapa varietas ubi jalar. *Jurnal Penelitian Pertanian Tanaman Pangan*, *24*(1), 8–18.

Harsojuwono, B. A., Mulyani, S., & Arnata, I. W. (2019). Characteristics of bio-plastic composites from the modified cassava starch and konjac glucomannan. *Journal of Applied Horticulture*, *21*(1), 13–19. https://doi.org/10.37855/jah.2019.v21i01.02

Hasanah, F., & Hasrini, R. F. (2018). Pemanfataan ganyong (*Canna edulis* Kerr) sebagai bahan baku sohun dan analisis kualitasnya. *Warta IHP (Warta Industri Hasil Pertanian)*, *35*(2), 99–105.

Hung, P. Van, & Morita, N. (2008). Distribution of phenolic compounds in the graded flours milled from whole buckwheat grains and their antioxidant capacities. *Food Chemistry*, *109*(2), 325–331. https://doi.org/10.1016/j.foodchem.2007.12.060

Imai, K. (2008). Edible Canna: A prospective plant resource from South America. *Japanese Journal of Plant Science*, *2*(2), 46–3.

Imran, Y. L., Hutomo, G. S., & Rahim, A. (2014). Sintesis dan karakterisasi bioplastik berbasis pati sagu (*Metroxylon* sp). *Agrotekbis : E-Jurnal Ilmu Pertanian*, *2*(1), 38–40.

Jabeen, N., Majid, I., & Nayik, G. A. (2015). Bioplastics and food packaging: A review. *Cogent Food & Agriculture*, *1*(1), 1117749. https://doi.org/10.1080/23311932.2015.1117749

Jading, A., Tethool, E., Payung, P., & Gultom, S. (2011). Karakteristik fisikokimia pati sagu hasil pengeringan secara fluidisasi menggunakan alat pengering cross flow fluidized bed bertenaga surya dan biomassa. *Reaktor*, *13*(3), 155–164. https://doi.org/10.14710/reaktor.13.3.155-164

Kamsiati, E., Herawati, H., & Purwani, E. Y. (2017). Potensi pengembangan plastik biodegradable berbasis pati sagu dan ubi kayu di Indonesia. *Jurnal Penelitian Dan Pengembangan Pertanian*, *36*(2), 67–76. https://doi.org/10.21082/jp3.v36n2.2017.p67-76

Kearsley, M. W., & Dziedzic, S. Z. (1995). *Handbook of Starch Hydrolysis Products and their Derivatives*. Glasglow: Blackie Academic & Profesional.

Khalil, H. P. S. A., Tye, Y. Y., Leh, C. P., Saurabh, C. K., Ariffin, F., Mohammad Fizree, H., … Suriani, A. B. (2018). Cellulose Reinforced Biodegradable Polymer Composite Film for Packaging

Applications. In *Bionanocomposites for Packaging Applications* (pp. 49–69). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-67319-6_3

Koswara, S. (2009). Teknologi Pengolahan Singkong (Teori dan Praktek). Bogor: Institut Pertanian Bogor.

Kumar, S., & Thakur, K. (2017). Bioplastics - classification, production and their potential food applications. *Journal of Hill Agriculture*, *8*(2), 118–129. https://doi.org/10.5958/2230-7338.2017.00024.6

Kuruppalil, Z. (2011). Green plastics: An emerging alternative for petroleum based plastics? In *IAJC-ASEE International Conference*. Hartford: Hartford University.

Lu, D. R., Xiao, C. M., & Xu, S. J. (2009). Starch-based completely biodegradable polymer materials. *Express Polymer Letters*, *3*(6), 366–375. https://doi.org/10.3144/expresspolymlett.2009.46

Malathi, A. N., Santhosh, K. S., & Udaykumar, N. (2014). Recent trends of biodegradable polymer: Biodegradable films for food packaging and application of nanotechnology in biodegradable food packaging. *Current Trends in Technology and Sciences*, *3*(2), 73–79.

Maryanti, E., Pasaribu, C., Adfa, M., Yudha S, S. P., & Fitriani, D. (2016). Pembuatan bioplastik berbahan pati ubi jalar (*Ipomoea batatas* L.), gliserin dan penambahan nanopartikel zno dengan menggunakan metode melt-intercalation. *Gradien : Jurnal Ilmiah MIPA*, *12*(2), 1175–1180.

Matsue, Y., Sato, H., Uchimura, Y., & Ogata, T. (2002). Influence of environmental temperature during the ripening period on the amylose content and whiteness of low-amylose rice. *Japanese Journal of Crop Science*, *71*(4), 463–468. https://doi.org/10.1626/jcs.71.463

Nadia, L., Wirakartakusumah, M. A., Andarwulan, N., & Purnomo, E. H. (2013). Karakterisasi sifat fisikokimia dan fungsional fraksi pati uwi ungu (*Dioscorea alata*). *Penelitian Gizi Dan Makanan (The Journal of Nutrition and Food Research)*, *36*(2), 91–102.

Noda, T., Kimura, T., Otani, M., Ideta, O., Shimada, T., Saito, A., & Suda, I. (2002). Physicochemical properties of amylose-free starch from transgenic sweet potato. *Carbohydrate Polymers*, *49*(3), 253–260. https://doi.org/10.1016/S0144-8617(01)00343-5

Puncha-arnon, S., Puttanlek, C., Rungsardthong, V., Pathipanawat, W., & Uttapap, D. (2007). Changes in physicochemical properties and morphology of canna starches during rhizomal development. *Carbohydrate Polymers*, *70*(2), 206–217. https://doi.org/10.1016/j.carbpol.2007.03.020

Santiago, G. T., Gante, C. R., García-Lara, S., Verdolotti, L., Di Maio, E., & Iannace, S. (2015). Thermoplastic processing of blue maize and white Sorghum flours to produce bioplastics. *Journal of Polymers and the Environment*, *23*(1), 72–82. https://doi.org/10.1007/s10924-014-0708-1

Sara, Y., Saleh, A., & Ramadani, K. (2018). *Sintesis dan Uji Kualitas Plastik Biodegradable dari Pati Kulit Singkong Menggunakan Variasi Penguat Logam ZnO dan Plasticizer Gliserol*. Jurusan Kimia. fakultas Sains dan teknologi. Universitas Islam Negeri Alauddin. Makassar.

Sit, N., Deka, S. C., & Misra, S. (2015). Optimization of starch isolation from taro using combination of enzymes and comparison of properties of starches isolated by enzymatic and conventional methods. *Journal of Food Science and Technology*, *52*(7), 4324–4332. https://doi.org/10.1007/s13197-014-1462-z

Sriroth, K., Chollakup, R., Piyachomkwan, K., & Oates, C. G. (2001). Biodegradable Plastics from Cassava Starch in Thailand. In *Cassava's Potential in Asia in the 21st Century: Present Situation and Future Research and Development Needs* (pp. 538–553). Ho Chi Minh City: Centro Internacional de Agricultura Tropical.

Suhery, W. N., Anggraini, D., & Endri, N. (2015). Pembuatan dan evaluasi pati talas (*Colocasia esculenta* Schoot) termodifikasi dengan bakteri asam laktat (*Lactobacillus* sp). *JSFK (Jurnal Sains Farmasi Dan Klinis)*, *1*(2), 207–214. https://doi.org/10.29208/jsfk.2015.1.2.36

Susanti, Malago, J. D., & Junaedi, S. (2015). Sintesis komposit bioplastik berbahan dasar tepung tapioka dengan penguat serat bambu. *Jurnal Sains Dan Pendidikan Fisika*, *11*(2), 179–184.

Szymońska, J., Targosz-Korecka, M., & Krok, F. (2009). Characterization of starch nanoparticles. *Journal of Physics: Conference Series*, *146*, 012027. https://doi.org/10.1088/1742-6596/146/1/012027

Thulasisingh, A., Kumar, K., Yamunadevi, B., Poojitha, N., SuhailMadharHanif, S., & Kannaiyan, S. (2021). Biodegradable packaging materials. *Polymer Bulletin*. https://doi.org/10.1007/s00289-

021-03767-x

Utami, N. W., & Diyono, D. (2011). Respon pertumbuhan dan produksi 4 varian ganyong (*Canna edulis*) terhadap intensitas naungan dan umur panen yang berbeda. *Jurnal Teknologi Lingkungan*, *12*(3), 333–343. https://doi.org/10.29122/jtl.v12i3.1242

Vankar, P. S., & Srivastava, J. (2018). A review-canna the wonder plant. *Journal of Textile Engineering & Fashion Technology*, *4*(2), 158–162. https://doi.org/10.15406/jteft.2018.04.00134

Widyatmoko, H., Subagio, A., & Nurhayati, N. (2018). Sifat-sifat fisikokimia pati ubi kayu terfermentasi khamir indigenus tapai. *Agritech*, *38*(2), 140–150. https://doi.org/10.22146/agritech.26323

Witthayanant, S. (2000). edible biennial plant head, *Canna edulis* Ker. CANNACEAE on white background. Retrieved from https://www.shutterstock.com/image-photo/edible-biennial-plant-head-canna-edulis-780937408