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REVIEW

State of the art of Indonesian agriculture and the introduction of innovation for added value of cassava

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Abstract

The dramatic population increase with rapid industrialization in developing countries has placed great strains on food and energy supplies. This is also the case for Indonesia. Despite having fertile volcanic soil and a strong agriculture tradition, these assets are under pressure, and strategies to preserve them from industrialization are urgently needed. Recently, the number and the interest to take on the profession of farmer have sharply declined, mainly due to urbanization. It should also be noted that the agricultural lands, both their area and fertility, have decreased. Farming has also become more challenging due to climate change. An alternative solution to revitalize the agricultural sector, increase the number of farmers, and increase their livelihood is urgently needed to ensure food security. For this reason, strengthening research activities in the field of crop biotechnology to improve agriculture production, human health, and social security is required. There should be multi-stakeholder collaborative efforts to develop reliable and environmentally sustainable approaches for agriculture. In this paper, our focus is on the application of biotechnology for cassava processing. Cassava was chosen due to it being the fourth largest staple food in the tropics and is well studied in Indonesia. In connection with improving the livelihood of cassava farmers, an introduction of bioprocess for the improvement of economic value of cassava tuber is highlighted, including an example of work for converting of cassava tuber to mycoprotein. In comparison with a commercial product, our results have shown comparable, if not better characteristics.

Keywords Cassava · Biotechnology · Agriculture · Indonesia

Introduction

According to Indonesian Statistics Bureau, the Indonesian population has increased significantly in the past decades. In 1971, the total number of population in Indonesia was 119,208,229 in 2010 became 237,641,326 and 265,000,000 in 2018. Agriculture is an important sector for Indonesia to secure food for a dense population. On the other hand, agricultural lands have decreased due to the conversion into non-agricultural sectors such as new city development, housing, industrial park, transportation. The fertility of the remaining agricultural land also decreases due to over fertilization and the use of chemicals. This affects food production indirectly that can threaten Indonesia's food security. It should be noted that the declining food production in the past few years has been coupled with the increasing number of food imports (Hidate 2015). Thus, Indonesia needs to produce more food for better food security. However, at the same time, business in the agricultural sector is now less attractive. Many people in rural areas, who were traditionally farmers, move to the cities through massive urbanization in search for better livelihood.

Indonesia is one of the richest countries in regards to natural resources. Indonesia has the second largest biodiversity in the world, including 800 types of food plants. Potential food plant species consist of 77 kinds of sources

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of carbohydrates, 75 kinds of sources of fat/oil, 26 kinds of beans, 389 types of fruits, 228 kinds of vegetables, 40 kinds of beverage ingredients, and 110 types of herbs and spices and seasonings. However, ironically, the Indonesian food security index is 64th (globally), which is far below that of Malaysia (33), China (38), Thailand (45), Vietnam (55), and the Philippines (63). It illustrates that Indonesia has experienced problems in the food security sector (Hidate 2015), particularly in utilizing its massive biodiversity.

Cassava (*Manihot esculenta*) is one of the most important food crops in many parts of the tropics, including Indonesia. Cultivation is easy, which has made cassava a major source of energy for millions of people (de Bruijn and Fresco 1989) and is also one single crop that is helping to alleviate food crisis problems (Hahn and Keyser 1985). Thus, cassava is currently playing an important role in solving the global food insecurity. It has a comparatively high biological efficiency of food-energy production and the ability to survive and grow under very adverse weather conditions. For Indonesia, with fertile volcanic soil and high sunlight energy, cassava has been cultivated intensively throughout the archipelago. Cassava plantation could be found easily in all provinces. In 2015 the total production of cassava could reach 21.801.415 tons even though the productivity is relatively low, only 22,951 ton/ha. The productivity of cassava can still be increased up to 100 ton/ha so that the potential of 95 million tons could be achieved.

In spite of these facts, cassava is often classified as an “inferior food crop” and as “poor people’s crop” (Hahn and Keyser 1985) and as a “dangerous crop” (Cheok 1978). These myths on cassava were due to some limitations in the crop. The major “limitations” of cassava as food include the presence of toxic cyanogenic glucosides, low protein content, and short postharvest shelf-life.

Traditionally, most of these constraints have been met through processing. Cassava is processed to remove or reduce toxic glucosides, improve palatability as well as serve as a means of preservation (Nambissan and Sundaresan 1985). Various traditional processing methods are known which include boiling, smoking, drying and fermentation. Fermentation of cassava is by far the most important and widely used means of processing cassava (Oyewole 1992). In Indonesia, fermentation of cassava using microbial consortium, particularly yeast, is used predominantly by the Sundanese Tribe in West Java. The product is called tapei and is a traditional delicacy in the region as sweet, sour and alcoholic traditional fermented food.

According to the Food and Agriculture Organization of the United Nations, the average minimum daily energy requirement is about 1,800 kcal (7500 kJ) per person. Indonesia is in ranked 109 globally with daily calorie intake of 2550 kcal (10,670 kJ). Even though the calorie intake is above the minimum required daily energy, a total number of 19.4 million people could not receive appropriate food and nutrition. FAO declares that by 1990s every people should be able to have access to sufficient food and nutrition. However, it is noted, that in 2016, 17% of children under the age of 5 were suffering from malnutrition. Indonesia, therefore, is suffering from malnutrition which manifested by high number of stunting (Lee 2014). Total protein intake for Indonesians is only 61.1 g/percapita/day, lower than Vietnam (77.70), Myanmar (81.90), and Cambodia (63.20) (Lee 2014). Today, priorities of protein sources are coming from animal protein, e.g., beef. Today, 30% of agricultural land in the world is occupied by cattle industries that contribute to around 15% global gas house emissions. Cattle industries are not only emitting methane gas but also consume a large amount of water. To produce 1 kg of beef cattle, 15,415 L of water is required. Innovative ways are needed to produce protein efficiently and environmental friendly (Heffernan 2017). For these reasons, improvement of productivity and nutrient quality of cassava can be a possible alternative. In this paper, plant biotechnology to improve cassava productivity and nutrient quality and innovative fermentation process to convert cassava tuber to protein is highlighted.

Plant biotechnology for cassava improvement

The role of cassava as the fourth largest source of calories in the world can be improved by using biotechnology. First of all, transgenic cassava plant can serve as the basis to explore molecular aspects of somatic embryogenesis and friable embryogenic callus production. In addition, complex plant–pathogen interaction analysis may help to fight bacterial diseases and look at candidate genes possibly involved in resistance to viruses and whitefly traits of cassava. Currently, transgenic mediated nutritional improvement and mass production of healthy plants by tissue culture and synthetic seeds and the perspectives of using genome editing and the challenges associated with climate change for further improving the crop are becoming a new interest for cassava improvement (Chavarriaga-Aguirre et al. 2016).

Narayanan et al. (2019) succeeded in overexpressing three *Arabidopsis thaliana* genes in cassava to improve accumulation of zinc and iron levels in cassava storage roots. The technology can be used for improving iron and zinc intake through consumption of cassava up to 40–70% of the average estimated requirements of iron and zinc for pregnant women and children. Another example for improving nutrient intake using cassava is reported by Amapu et al. (2019), where they analysed the improvement of nutrition in wheat–cassava flour dough through fermentation by *Saccharomyces cerevisiae* and *Lactobacillus plantarum*.

Cassava root tubers are not the only nutrition source from the cassava plant. Its waste, which includes leaves and bagasse, can also be a good source of high-nutrition food, as reported by Ginting (2018), who fermented cassava leaves and roots. In addition, Morales et al. (2018) reported that cassava bagasse and leaves that are fermented with solid-state fermentation showed high content of essential amino acids and important unsaturated fatty acids. Indicating that with further investigation, waste from cassava (leaves and bagasse) can be a good source of food with high nutrition.

Biotechnology has been identified as a scientific tool that could be used to meet the current challenges in the traditional fermentation processing of cassava (Bokanga 1992). In Africa, fermentation is an important mean of processing raw cassava root into food. The role of various microorganisms in fermentation processes have been shown to include that of detoxification, flavour development and preservation. The major feature of cassava fermentation is a solid-state fermentation by the West African "gari" or the Brazilian "fariha de mandioca". Peeled cassava roots are grated, packed into polypropylene or jute sacks and subjected to pressure using heavy weights or hydraulic pressure for 3–5 days of fermentation (Okafor 1977; Ofuya et al. 1990). The fermented mass is further dewatered, sieved and roasted (*garification*) before consumption. Cassava roots may be cut into pieces or sliced before being spread out in the open air or under the sun (Essers, Nout 1989). The dried products are milled into flour and cocked into a stiff dough before consumption with sauce. Essers, Nout (1989) reported that moulds predominate in such products yielding dark-coloured, dry cassava pieces. The moulds found were *Rhizopus* spp., *Mucor* spp., *Peaicilliurn* spp., and *Fusarium* spp. The products of mould-fermented cassava have been reported to be safe.

Another fermentation process of cassava is a submerged fermentation. Cassava roots, peeled or unpeeled, whole or cut into pieces, are soaked in water for 2–7 days. The fermented roots may be wet-sieved and the mash cooked in boiling water to a stiff dough called fufu in Nigeria (Oyewole and Odunfa 1989) or subjected to further processing which may include sieving, sundrying, smoking and milling into flour and then cooked to stiff dough called lafun in Nigeria (Oyewole and Odunfa 1988). The submerged fermentation of cassava is mainly acidic. The pH of the cassava roots decreases from 6.5–6.9 to 3.8–4.1 after 84 h of soaking in water. A wide spectrum of microorganisms have been implicated in cassava fermentations: *Bacillus* spp., *Leuconostoc* spp., *Klebsiella* spp., *Corynebacterium* spp and *Lactobacillus* spp. (Oyewole and Odunfa 1988). The latter period of the fermentation was dominated by yeasts and lactic acid bacteria. Lactic acid bacteria are an important group of microorganisms which have been consistently isolated from fermenting cassava (Ngaba and Lee 1979; Oyewole and Odunfa 1988). Submerged fermentation affects carbohydrate, protein and mineral contents of cassava roots (Oyewole and Odunfa 1989). Fermentation also causes a reduction in starch content while the total soluble and reducing sugar levels are increased during the first 36 h and 24 h, respectively. Sugars are reduced during the latter periods of fermentation due to utilization by microorganism and the conversion of sugars into organic acids. Fermentation also causes increases in cassava calcium levels (12%) with reduction in manganese (53%), potassium (71%), sodium (68%), iron (50%), copper (7%), zinc (85%) and phosphorus (67%) levels.

Microbial conversion of cassava tuber to mycoprotein

Rhizopus oligosporus has being domesticated for more than century by Javanese Tribe in Java Island. It is the key element in the production of tempe. Tempe is a traditional fermented food of Indonesia origin. It is a compact, cheese-like and high-protein food made of cooked soybeans fermented with a *Rhizopus fungus* and used as a meat substitute for many Indonesian diets. The use of tempe mould is now being spread out globally. This mould has unique characteristic and has high degrading as well as synthesizing powers. The mould is equipped with complete enzymatic system including in particular amylases. This mould could actually be grown in submerged fermentation on cassava starch medium and convert cassava starch directly to mycelial biomass rich in protein (mycoprotein) (Sukara and Doelle 1987, 1988a, b, c, 1989a, b). In addition, the remaining broth is full with amylase enzymes. For this reason, tempe mould could be used for the production of mycoprotein and amylase enzymes in one-step fermentation process in submerged fermentation using cassava starch as a sole carbon and energy source (Sukara and Doelle 1987). Furthermore, *Rhizopus* has received the designation Generally Recognized to be Safe (GRAS) from the US Food and Drug Administration (FDA) (Canedo et al. 2016), which makes it a viable choice for developing new products for human consumption.

The production of mycoprotein from cassava tuber may be carried out through submerged fermentation using *R. oligosporus* in bubble column fermenter as described by Sukara and Doelle (1989a, b). The use of cassava tuber could reduce the cost as the starch separation can be eliminated while the product, mycoprotein, contains high degree of fibre.

Cassava tuber is sliced, dried and powdered. To improve mycoprotein concentration, the amount of 10% (w/v) of cassava powder is used. The cassava powder is suspended in demineralised water and pH adjusted to 4.0. The amount of 0.5% (w/v) of technical grade ammonium sulphate and 0.1% of technical grade magnesium sulphate are added. To prevent gelation of starch and to ease agitation of the starch based-medium, 0.1% (w/v) of amylase enzyme is added. Amylase is prepared by germinating paddy grains at humidized jars for 8 days, germinated paddy grain is dried at 50 °C overnight and ground to obtain crude amylase powder. The mixture is heated in boiling water bath for 15 min and transferred aseptically to a sterilized bubble column fermenter. Let it cool to 45 °C and inoculate with 0.2% (w/v) of *Rhizopus* spore powder. Sterile air is introduced to provide oxygen and to gently mixe the medium but prevent the damage of shear sensitive mycelium. Incubate the culture for 72 h at room temperature. Mycelium will grow progressively and form like cotton in the medium followed with complete starch utilization. The fermented product is harvested and distributed to a tray as a thin layer and dried at 50 °C overnight until dry and crisp and ground to become a mycoprotein. The conversion efficiency of cassava tuber to mycoprotein powder could be as high as 84%.

For the production of mycoprotein using cassava as raw material by tempe mould, *R. oligosporus* should have a great advantage for the production of raw material of food industries. Since 1990, FAO declares that each individual should have an easy access to good food and nutrition. According to the data in 2016, children under the age of 5 are suffering from malnutrition. Indonesia is experiencing the most difficult situation with at least 17% of children suffering from malnutrition and the worst among ASEAN countries. The occurrence of stunting is high (Lee 2014). The main cause is that the total protein intake is low. It is only 61.1 g/capita/day, or lower compared to Vietnam (77.70), Myanmar (81.90), and Kamboja (63.20) (Lee 2014). For this reason, Indonesia has to improve daily protein intake. The minimum daily protein intake would be difficult to achieve through dependency on animal protein, e.g., milk and meat, due to the price of those protein sources. A new innovation is urgently required, and mycoproteins could be one choice. A mycoprotein-based product has been developed by a company in UK, Rank Hovis McDougall (RHM). They proved that mould could replace meat protein. They are using *Fusarium venenatum* and grain as a substrate for making mycoprotein. The product is introduced with the brand name Quorn™ which was launched in 1985 (Wiebe 2004).

In our experiment, we also proved that *R. oligosporus,* the tempe mould, could be developed for the production of mycoprotein in submerged fermentation using ground cassava tuber as substrate. With using tempe mould, it should become a safer product since the mould has already been around in food industries for more than century (Sukara and Doelle 1988a; b). Mycoprotein can be produced using tempe mould isolate JT-020518-SU. High concentration of cassava tuber up to 30% may be used. To prevent gelation and to ease mixing in submerged fermentation, α-amylase enzyme is used. The addition *α*-amylase is necessary to liquefy starch. When the mycelial biomass and the fermentation broth homogenized and dried, the conversion efficiency of starch to mycoprotein could be as high as 63–81% with the protein content of 18–23% or 1.8 times compared to egg, 1.2 times compared to beef or 1.3 times compared to chicken. When it is compared with Quorn-based product (illustrated in Fig. 1a, b), protein content is higher, saturated fat slightly lower, unsaturated fat and total fat lower. No cholesterol is detected. Carbohydrate content calorific value and raw fibre is higher (Progress Report Surya University on CPPBT-PT Project 2018).

Conclusion

The application on plant biotechnology could improve productivity and the production of cassava, but it would be difficult to improve its nutritive value. Conversion of cassava through microbial processes may add to the value of cassava is a lot easier due to high degrading power and synthetics capacity of microbe. Cassava may also be converted to high-value and demanded product, such as mycoprotein, through fermentation process in submerged fermentation. *R. oligosporus*, a mould used in tempe industries and known as Generally Recognized as Safe (GRAS) by the US FDA, would be a promising candidate for the production high-quality protein in the future. The combination of cassava cultivation and the use of community-based biotechnology for cassava added value should be developed to attract farmer interest in agricultural sector. This effort may provide solutions to some of the SDG targets such as the no poverty, zero hunger, good health and well-being, industry, innovation and infrastructure, and life on land SGDs.

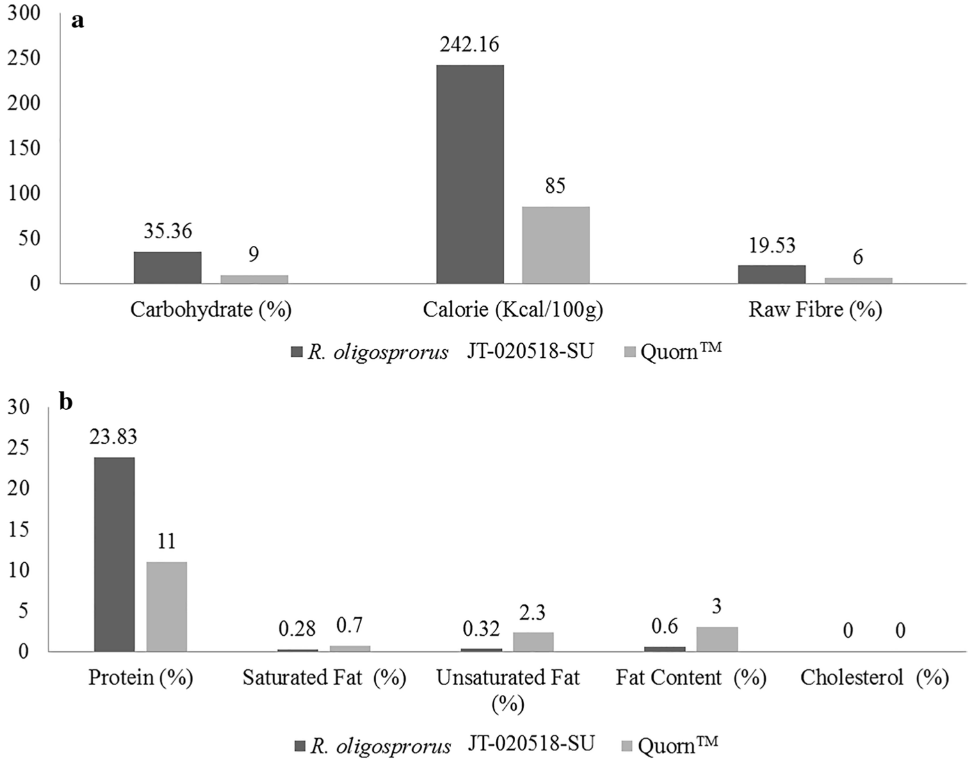

Fig. 1 Comparison of composition of carbohydrate, calorie and raw fibre (**a**) and protein, saturated fat, unsaturated fat, fat content and cholesterol (**b**) of fermented cassava using *R. oligosporus* JT-020518-SU (the authors' research) and Quorn™'s mycoprotein product

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