Dioscorea hispida: economic potential and applications

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Abstract. *Dioscorea hispida* is one of the 600 edible plant species belongs to Dioscoreaceae family. It is distributed in tropical and sub-tropical regions of Philippines, China, Taiwan, New Guinea, Malaysia, Fujian, Bhutan, Indonesia, Bangladesh, Sikkim, Thailand, Cambodia, Laos, Myanmar, Vietnam, and Africa. Each of the mature plant can produce up to 15 kg of tuber. However, it is economically insignificant due to the presence of toxic alkaloid dioscorine in the fresh tuber. The economic value and potential applications of *D. hispida* tuber starch will be discussed. Starch from *D. hispida* tuber has been researched for the applications in food and non-food industries. The starch was used as material in water filtration system, wastewater treatment, and thermoplastic film. The starch was also used as a food ingredient, and it can be further value added by converting it into glucose syrup and oligosaccharides prebiotic. Paste of *D. hispida* tuber has been shown to have ethno-pharmaceutical value in treating wound, vomiting and eye infection, and the fermented tuber (*tape* or *tapai*) has been shown to have health benefits in reducing hypertension and blood cholesterol level.

1. Introduction

Dioscorea hispida (or commonly known as yam) is a perennial monocotyledous tuber-producing climbing plant (**Figure 1**) which naturally thrives in tropical and sub-tropical regions of Philippines, China, Taiwan, New Guinea, Malaysia, Fujian, Bhutan, Indonesia, Bangladesh, Sikkim, Thailand, Cambodia, Laos, Myanmar, Vietnam, and Africa [1,2]. Although there are 1137 species of *Dioscorea*, only about 600 species are edible and *D. hispida* is one of them. Each mature plant of *D. hispida* can produce up to 15 kg of starchy tuber (**Figure 2**) which however contains water soluble toxic alkaloid dioscorine [3].

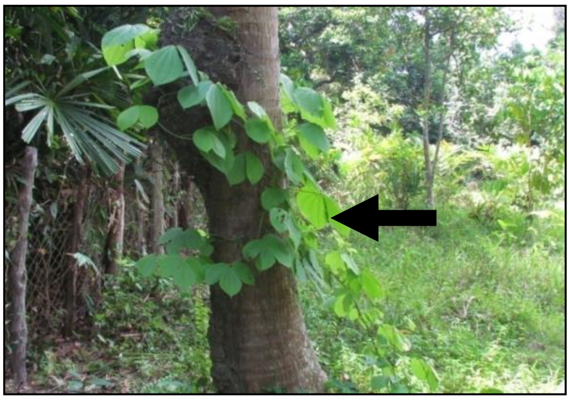

Figure 1. *D. hispida* climbing plant

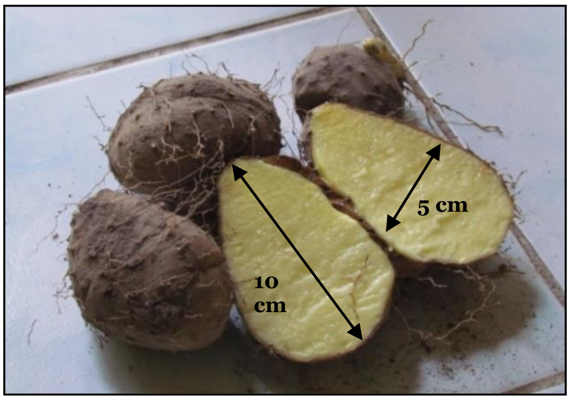

Figure 2. Tubers of *D. hispida*

The presence of dioscorine has negatively impacted the value of the starchy tubers. Nevertheless, traditional method of steeping the tubers in flowing water has successfully removed the toxin to a safe consumption level, and one kg of fresh tuber can produce up to 270 g of starch powder. Therefore, the economic value and potential applications of *D. hispida* tuber starch will be explained in this paper.

2. Composition and physical properties of starch from *D. hispida* tuber

The starch was processed from *D. hispida* tubers obtained from Marang, Terengganu, Malaysia following these steps: washing and peeling the tubers, slicing the tuber into thin slices, submerging the slices in 5% of NaCl solution for 3 days, grinding the slices, separating the slurry, collecting the filtrate, sedimentation of the starch and drying of the starch [4]. *D. hispida* starch powder contained (in dry basis) 0.42% total crude protein, 0.23% total crude fat, 0.47% ash, and 98.88% carbohydrate. The carbohydrate was mainly starch (88.8%) with amylose to amylopectin ratio of 28:72.

The proximate analysis in dry basis of *D. hispida* starch in comparison with other commercial starches (corn, sago, and potato) is shown in **Table 1** (Napisah, 2019).

Table 1. Proximate analysis of *D. hispida* and some commercial starches.

	Crude Protein	Crude Fat	Ash	Carbohydrate
D. hispida	0.42	0.23	0.47	98.88
Sago	0.22	0.14	0.19	99.45
Potato	0.13	0.11	0.43	99.33
Maize/corn	1.00	0.11	0.23	98.66

The crude protein content of the starches ranged between 0.13% and 1.00% (**Table 1**), and corn starch contained the highest protein. *D. hispida* starch contained the highest crude fat (0.23%) and its ash content (0.47%) was similar with potato but higher than sago and corn starches. Ash content is an indication of mineral content of a food. This therefore suggests that *D. hispida* starch could be an important source of mineral. All the starch sources had high carbohydrate content of over than 98%.

The physical property of *D. hispida* tuber starch is shown in **Table 2** (Napisah, 2019).

Table 2. Physical property of *D. hispida* tuber starch.

Parameter	Value
• Granular size and morphology	2-4 µm, polyhedral shape
• Bulk and tapped density	290 kg/m^3, 410 kg/m^3
• Swelling power and solubility capacity	14.22 g/g, 5.48%
• Water-holding and oil-holding capacities	2.78 g/g, 1.14 g/g
• Pasting property	Pasting temperature 78.15°C; peak time 5.87 min;

	peak viscosity 283.50 RVU
• Diffraction pattern	B-type starch

The granules of *D. hispida* starch were observed at 5000× and 10000× magnifications using a scanning electron microscope as shown in **Figure 3**. The granules were of polyhedral shape with coarse surfaced without fissure. The average diameter of *D. hispida* starch granule was 2-4 µm, the smallest granule if compared to other species of *Dioscorea* (23-40 µm) [5]. *D. hispida* starch granule was also the smallest as compared to that of sago (20-40 µm), potato (15-75 µm), and corn (8-12 µm). The compact and small granules make *D. hispida* starch has higher gelatinization temperature than corn starch. This is because corn starch granule has relatively weaker granular structural integrity due to the presence of natural pores and cavities on its surface [6].

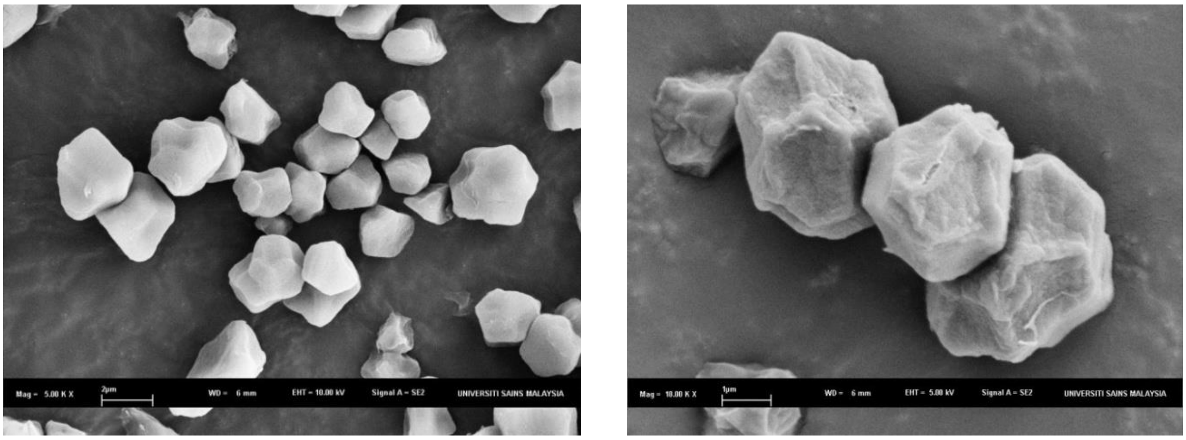

Figure 3. Scanning electron micrographs of *D. hispida* starch granules. Left, 5000×; Right, 10000×

3.1 Non-food industries

There are some potential applications of *D. hispida* tuber starch in non-food industries. Some but not limited examples are discussed here.

3.1.1 Coagulant in wastewater treatment. Starch from *D. hispida* tuber is used as natural coagulant, an alternative to environmental detrimental chemical coagulant in textile wastewater treatment [7]. Textile mill wastewater is a high turbidity effluent which contains large content of dyes, significant amount of suspended solids that contributes to high COD concentration. Incorporation of 2.5 g *D. hispida* starch per L of textile mill effluent at pH 7, managed to remove COD, turbidity, and colour of the effluent by 28%, 94% and 64% respectively.

3.1.2 Component in thermoplastic film. Chemical composition and physical property of starch and fibre waste from *D. hispida* tuber were analysed for the suitability as filler material for biodegradable thermoplastic film composite [8]. The experiment revealed that the starch and fibre have excellent thermal stability and high decomposition temperature of 309.7°C and 315.4°C, and crystallinity index of 27.5% and 39.0%, respectively. It was concluded that starch and fibre waste of *D. hispida* tuber could be promising alternative sustainable biomass materials as renewable filler materials in food packaging application.

3.1.3 Antifungal agent. Another application of *D. hispida* tuber starch is as an antifungal agent in wood decaying prevention [9]. An antifungal coating film containing *D. hispida* tuber starch to prevent wood decay was developed. Rubber wood coated with a modified film coating formula with a ratio of 2:1:1:1 (polyvinyl alcohol: starch: sorbitol: hexamethylenetetramine) was able to retain approximately 50% of its original weight. Moreover, the coating film was effective to inhibit the growth of fungi *G. trabeum* and *C. versicolor*.

3.1.4 Component in water filtration membrane. *D. hispida* starch was used as the material in water filtration membrane. This is achieved by constructing a forward reverse membrane made of a glutaraldehyde-crosslinked chitosan and *D. hispida* starch (3% chitosan, 1.5% *D. hispida* starch, 5.6×10^{-5} mol glutaraldehyde, and 0.4% glycerol) into a fabricated water filtration bag [10]. It was concluded that the filtered brackish water using the filtration bag with chitosan/*D. hispida* starch membrane had met the quality standards for drinking water by WHO.

3.2 Food industry

3.2.1 Starch as food ingredient. *D. hispida* starch has been researched to be used as food ingredient in replacing a certain percentage of wheat flour in the making of muffin, cookies and bread, and these food products have gained good customers' acceptance. Therefore, *D. hispida* starch has the potential as a food ingredient in bread and confectionary. As a result, large quantity of *D. hispida* starch is needed to fulfill the industrial demand. Cell wall of *D. hispida* tuber contains up to 48.2% cellulose and pectin. Cell wall degrading enzymes such as cellulase and pectinase are commonly used to degrade the cell wall components to release the intracellular content.

Enzymatic approach was attempted to obtain a higher yield of starch extraction from *D. hispida* tuber. Cell wall degrading enzymes (cellulase, pectinase or combination of cellulase and pectinase) were added into *D. hispida* tuber pulp. After the enzyme reaction was terminated, starch slurry was left to sediment and the extracted starch was dried. **Table 3** shows the enzymatic reaction condition, yield of starch and percent increase in starch yield after incorporating cell wall degrading enzymes during the starch extraction method.

Table 3. Yield of extracted starch as affected by cell wall degrading enzymes.

Sample	Enzyme Reaction Condition	Yield of Starch (%, w/w)	% Increased
Without enzyme (Control)	-	27.00	-
Cellulase (C)	pH 5, 37°C, ratio 1:2, 2 h	39.15	45
Pectinase (P)	pH 4, 50°C, ratio 1:2, 3 h	35.78	29
Combination C and P	pH 4.5, 45°C, ratio 1:2, 2 h	51.98	97

Note: The enzyme reacted with tuber pulp at a ratio of 10 unit of enzyme to 10 g, 20 g or 30 g of pulp for a duration of 4 h with interval sampling.

The yield of the extracted starch was increased by 45%, 29% and 97% by using cellulase, pectinase, and combination of cellulase and pectinase (unpublished data), respectively as compared to the control sample which was extracted according to the conventional starch extraction method [4].

3.2.2 Glucose syrup. *D. hispida* tuber starch can be further processed to glucose syrup. Starch polysaccharides consist of amylose and amylopectin. Amylose is a linear polymer of glucose linked by α-1-4 glycosidic bonds and amylopectin is a branched polymer of glucose linked by α-1-4 and α-1-6 bonds. The glucose syrup was obtained by treating the gelatinized *D. hispida* starch with a consecutive action of α-amylase and glucoamylase [11]. **Table 4** shows the enzymatic reaction condition.

Table 4. Enzymatic reaction condition.

Sample	α-amylase	Glucoamylase
Gelatinized starch	pH 6.9, 70°C, 60 min	pH 4.5, 60°C, 40 min

Note: Enzyme was maintained at 1 U per 2 g of starch. Reaction was allowed to occur for 90 min for each enzyme and interval sampling was carried out for total reducing sugars concentration analysis.

α-amylase hydrolyzed amylose polymer into oligosaccharides and maltose. Reacting the starch polysaccharides with α-amylase for 60 min had increased the total reducing sugars concentration as maltose by 148%. The mixture was consecutively reacted with glucoamylase for 40 min and the final mixture had a total reducing sugars concentration of 4.42 mg/mL dextrose equivalent value of 42%. Glucoamylase hydrolyzed disaccharides maltose to glucose monomers. As a result of the enzymes reaction, the starch polysaccharides were fully hydrolyzed to glucose and fructose as determined by using a HPLC system. *D. hispida* glucose syrup had a dextrose equivalent value of 42% with 99.7% of the sugars were glucose and 0.3% was fructose.

3.2.3 Oligosaccharides prebiotic. Starch was extracted from *D. hispida* and further processed to oligosaccharides via enzymatic hydrolysis (Napisah, 2019). The oligosaccharides were evaluated for their prebiotic potential which are resistant to gastric acid and gastrointestinal enzymatic digestions, resistant to intestinal absorption. The prebiotic oligosaccharides should be metabolized by beneficial intestinal microflora and producing short chain fatty acids.

D. hispida oligosaccharides was obtained from the starch hydrolysis with sequential action of α-amylase and pullulanase on 10% (w/v) starch for 6 hours. The yield of oligosaccharides produced was 19.3 mg g^{-1} of starch and mixture with degree of polymerization (dp) of 2-7 was separated and used for prebiotic potential study (**Figure 4**).

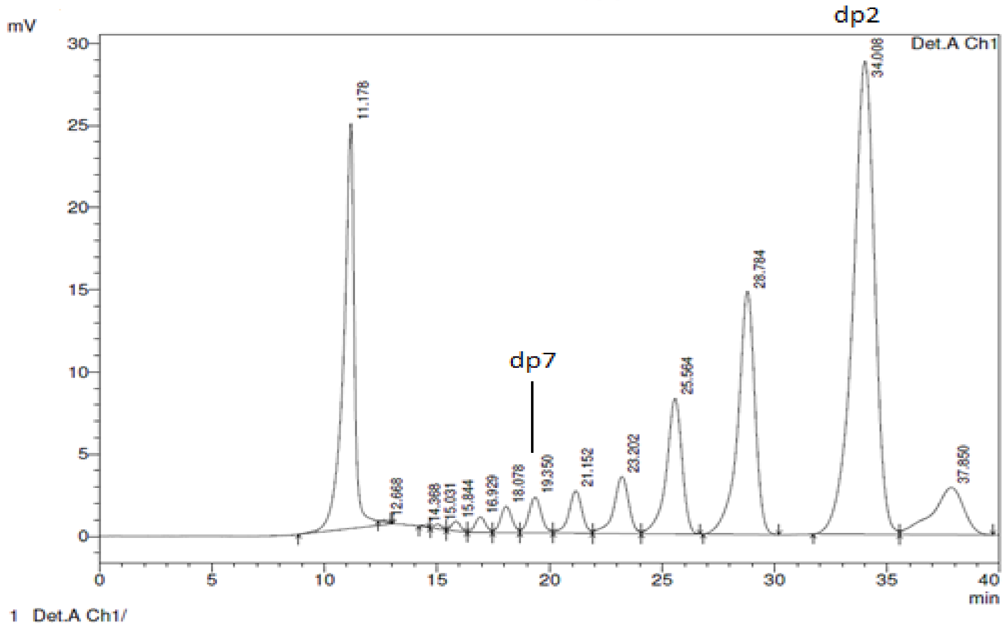

Figure 4. HPLC chromatogram of DHOS obtained after hydrolysis of 10% (w/v) *D. hispida* tuber starch by sequential activity of α-amylase and pullulanase for 6 h

The oligosaccharides were subjected to gastric juice digestion at pH 1-pH 4 for 180 h. The oligosaccharides were partially digested at high acidic pH 1 and pH 2 but resisted the digestion by the gastric juices at pH 3 and pH 4.

The oligosaccharides were also subjected to gastrointestinal tract digestive enzymes; salivary α-amylase, and pancreatic pepsin and pancreatin. At least 64% of the oligosaccharides were still intact and more than 50% of the *D. hispida* oligosaccharides retained in the dialysis tubing, indication of its resistance towards digestive enzyme hydrolysis and intestinal absorption.

Incorporation of *D. hispida* oligosaccharides in the culture medium of selected beneficial bacteria was able to enhance the bacterial growth, reduce the pH medium, produce substantial amount of lactic, acetic, and propionic acids, and exhibited positive prebiotic activity score [12]. In conclusion, oligosaccharides of *D. hispida* tuber starch have the potential to be used as a dietary prebiotic ingredient.

4. Pharmaceutical Benefits

4.1 Ethnobotanical use and ethnopharmacological use

Although the pharmaceutical benefits of *D. hispida* tuber have not been scientifically proven, native people around the world has been using the tuber for (a) eye treatment by applying the eye with water of soaked tuber, (b) foot skin treatment by pasting the tuber on the affected parts overnight to treat the peeling of skin, (c) treatment of vomiting, indigestion, and used as a purgative, (d) wound and injury treatment by applying roasted tuber paste on the affected area. Kumar and co-workers had studied on the ethnopharmacological potential and traditional use of *Dioscorea* species by the local people of Similipal Biosphere Reserve, Odisha, India [13].

Besides providing energy source from the dietary starch carbohydrate, tuber of *Dioscorea* species possess various secondary metabolites which are responsible for the medicinal properties of the tuber. Bioactive compounds identified in *Dioscorea* species were saponins, alkaloids, flavonoids, tannin, phenols, allantoin (a purine derivatives), furanoid norditerpenes cyanogens, and lutein. Allantoin was found to be in higher concentration in *Dioscorea* species than in any other plants (Fu et al., 2006). Therefore, it was recommended that allantoin be a standard compound for the quality control of *Dioscorea* tubers. Allantoin inhibits the activity of α-amylase and α-glucosidase which is responsible for its antihyperglycemic/antidiabetic action. Furthermore, it has antioxidant and antidyslipidemic activities.

Fermented *Dioscorea* sp. tuber (*tape* or *tapai ubi*) with red mold (usually is *Monascus* sp.) has been proven to have antihypertensive, antidiabetic, antilipidemic and anticancer activities.

4.1 Antihypertensive agent

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) of hypertensive rats, orally administered with 75 mg fermented *Dioscorea* per kg of body weight for 8 weeks, decreased significantly. Administering 150 mg/kg of fermented *Dioscorea* to the rats had significantly reduced the SBP and DBP after 8 h of administration. This is because the fermented *Dioscorea* contained γ-aminobutyric acid, anti-inflammatory yellow pigments (monascin and ankaflavin), and angiotensin-l-converting enzyme (ACE) inhibitory activity (Wu et al., 2009).

4.2 Antidiabetic and antistress agent

Fermentation of *Dioscorea* tuber with red mold produced a yellow pigment monascin. This pigment showed antidiabetic activity in streptozotocin-induced diabetic rats. Blood glucose and serum insulin of the rats which were fed with 30 mg monascin/kg/day for 8 weeks was attenuated and increased respectively (Shi et al., 2012). The same group of researchers also studied the effect of monascin from the fermented *Dioscorea* on the lifespan of *Caenorhabditis elegans* under a high-glucose condition, and it was found that monascin increased stress resistance and expression of the stress response genes, thus extended the lifespan of the *C. elegans*.

4.3 Antilipidemic activity

Monacolin K (lovastatin) is a secondary metabolite produced by *Monascus purpureus* during the fermentation of *D. hispida* tuber with red mold. Monacolin K is an inhibitor for HMG-CoA reductase in cholesterol biosynthesis. Fermented *Dioscorea* exhibited higher anti-cholesterol activity than fermented rice because monacolin K production was higher in the fermented *Dioscorea* (Lee et al., 2010). Besides monacolin K, yellow pigments monascin and ankaflavin produced during the fermentation had also shown significant effect on lowering cholesterol, triglyceride, and low-density lipoprotein cholesterol levels in the blood serum and aorta lipid plaque of the tested hyperlipidemic rats (Lee et al., 2010).

4.4 Anticancer activity

Ethanolic extract of fermented *Dioscorea* tuber with red mold was tested for its anti-cancer effect on cancer-induced hamster. The carcinogenesis of buccal pouch of the hamster was induced by 7,12-dimethyl-1,2-benz[a]anthracene (DMBA). The ethanolic extract had shown therapeutic potentials against oral cancer as it had decreased nitric oxide, reactive oxygen species, and prostaglandin E2 overexpression, and simultaneously increased p53, serum tumor necrosis factor-α (TNF-α), and interleukin-1β (IL-1β) to significantly stimulate caspase-8 and -3 activities, indicating that the extract had managed to reduce oxidative damage caused by DMBA and induced apoptosis in the oral cancer cells (Hsu et al., 2011).

5. Conclusion

D. hispida tuber has gained great attention due to its starch content. Starch of *D. hispida* tuber has potential use in food (as starch, oligosaccharides, and glucose syrup) and non-food industries (as thermoplastic film, antifungal agent, filtration membrane and coagulant). Secondary metabolites from fermented *D. hispida* tuber with red mold have been researched for their pharmaceutical benefits as antihypertensive, antidiabetic, antilipidemic and anticancer agent.

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