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PHYSICAL, THERMAL AND FUNCTIONAL PROPERTIES OF FLOUR DERIVED FROM UBI GEMBILI (*DIOSCOREA ESCULENTA* L.) TUBERS GROWN IN INDONESIA

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ABSTRACT

Gembili (*Dioscorea esculenta* L.) tuber is one of the important food sources in term of cultural, nutritional and economic perspectives for the people in the Africa, Caribbean islands, Asia, and Oceania regions. The tubers can be eaten after being boiled, roasted, fried or cooked. However, there is lack of information on the advanced utilizations of the tubers as raw material in the manufacture of modern foods. This study aims to characterize the physical, functional and thermal properties of Gembili flour, so that this information can be used as the basis in the development of novel foods. The microstructure, crystallinity, gelatinization temperature, swelling power and solubility of the flour were determined. The electron microscope observation revealed that Gembili flour consisted of smooth surface oval granules, which were light brown in color and having 23 µm average diameter. They are comprised of polygonals or some clusters of irregular fragments. Similar to most of tuber flours, Gembili flour also exhibited B-type crystallinity with approximately 31 ±3.7% crystallinity. The gelatinization temperature of Gembili flour was high and being comparable to that of cereal flour. The enthalpy of gelatinization of Gembili flour (9.52 ±0.80 $J.g^{-1}$) was comparable to that of *Dioscorea alata*. Unfortunately, Gembili flour exhibited low swelling power (3.90 ±0.01 $g.g^{-1}$). The Gembili flour granules were highly soluble in water (11.07 ±0.05%). Based on those reported properties, Gembili flour can be a suitable raw material for the manufacture of bakery, cookies, noodle and infant foods.

Keywords: *Dioscorea esculenta*; flour; physicochemical properties; functional properties; thermal properties

INTRODUCTION

Yams are the edible tubers of numerous species of the genus Dioscorea, which contain high content of starch as excellent sources of caloric energy **(Coursey and Ferber, 1979)**. The primary cultivation areas of yams are in the West, some parts of East, Central and Southern Africa **(FAO, 2001)**, which produce about 95% of the total world's yam production. The second largest yams producing areas are located in the Asian regions including China, Japan, Indonesia, Malaysia, Philippines and Oceania. The third growing areas include the Caribbean, Mexico, and parts of Central America **(FAO, 2001)**. Uwi (*Dioscorea alata*) and Gembili (*Dioscorea esculenta* L.) are the two main yam species commonly found in Indonesia, which can be harvested after being cultivated for 7 – 9 months. They are seasonal crops and generally planted in the end of September to October. The yellowing leaves and withered vines are strong indications of mature crop, which is usually ready to harvest around May to July **(Senanayake et al., 2012)**. Figure 1 (a) and (b) presents the Gembili plant and its tuber. Further, **Senanayake et al., (2012)** reported that the flour Gembili tubers planted in Sri Lanka contains 10.39 ±0.15% moisture, 1.50 ±0.20% lipid, 9.02 ±0.65% protein, 2.10 ±0.20% ash, 2.33 ±0.15% fiber and 74.66 ±0.66% carbohydrate. Similarly, **Ukpabi (2010)** also reported a comparable proximate composition of the flour of *D. esculenta* grown in Nigeria. Unfortunately, yam tubers are known to contain different toxic substances that affect both human and animals when they are consumed, despite their high nutritional values **(Polycarp et al., 2012)**. **Yang and Lin (2008)** reported that the age, the cultivar, the geographic locality of a plant or the storage condition after harvest could significantly affect its anti-nutritional content.

In most parts of Indonesia, yams tubers are only consumed as additional foods after being boiled, steamed, roasted, fried, baked or cooked. In contrast, yams are utilized as staple foods **(Coursey and Ferber, 1979)** and being important sources of ingredients for manufactured foods, which play a key role in the socio-economic and cultural lives of both growers and consumers in many


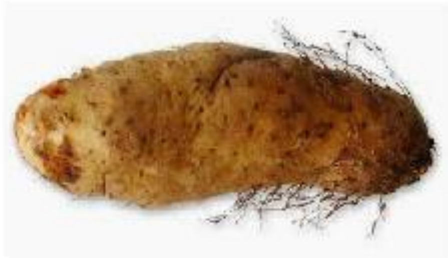

Figure 1 Ubi Gembili plant (a) and its tuber (b).

tropical countries in West Africa, the Caribbean islands, Asia, and Oceania **(Girardin et al., 1998)**. Primarily, the utilizations of yam have been limited to the preparation of traditional dishes, such as pounded yam and porridges. To prepare pounded yam, the yam tubers are usually sun-dried and powdered into flour for reconstituting into a stiff paste (amala), which is consumed with preferred vegetable soup **(Awoyale et al., 2010)**. In regard to their fiber contents, yam flours also provide health benefits especially in the prevention of obesity, constipation, cardiovascular disease, diabetes and colon cancer **(Chen et al., 2003)**. Interestingly, the absence of gluten has promoted yam flours as promising nutrition sources for those who suffer celiac disease (CD) **(Van Hung and Morita, 2005)**.

Considering that yam tubers are highly perishable and bulky, they are commonly processed into flour and starch as the most acceptable forms, in which they are usually consumed or stored. These types of product provide a higher possibility to prolong the supply of yam during the off-season, thereby decreasing the loss during storage and reducing the cost for marketing and transportation **(Coursey and Ferber, 1979)**. However, the potential utilizations of yam flours have not been fully understood, mainly due to lack of general knowledge on the suitable processing techniques and product development as well as the physicochemical and functional properties of these plant materials. Flour characteristics, such as granule size, crystallinity, swelling power and solubility pattern, pasting behavior and gelatinization properties are important in the design and manufacture of high quality food products **(Aprianita et al., 2014a)**. This valuable information could also enable the food processors to modify the flours if necessary to accommodate the product and processing demands. Interestingly, flour and starch from tubers and roots can be used to substitute wheat flour in certain food applications, especially in the manufacture of biscuits and bakery products such as cookies, bread and cakes to reduce the production cost **(Adeleke and Odedeji, 2010)**.

Due to its large population, Indonesia requires a relatively high quantity of rice and wheat as the main sources of carbohydrates, which is mostly fulfilled by import and triggered a large financial burden. This high import dependency is mainly caused by the unsuitability of the tropical climate for the cultivation of wheat in this country. Improving our knowledge of the properties of Gembili tubers grown in Indonesia and many other countries may result in the wider applications in the food or non-food industry. This will also contribute to the reduction of dependence on wheat flour as the main source of carbohydrate in Indonesia and other non-wheat growing countries.

Scientific hypothesis

The objective of this research was to determine the physical, thermal, and functional properties of Gembili (*D. esculenta*) tuber flour as an important part of efforts to widen the possible applications of Gembili flour within the food industries, particularly biscuits and noodles.

MATERIAL AND METHODOLOGY

Samples of plant material

The freshly harvested 9 months age Gembili tubers grown in Gunungpati, Semarang-Indonesia (geographical location: +7°5'13.39" S latitude, +110°21'27.69" E longitude and 285 m altitude) were purchased from the traditional market in Semarang-Indonesia, in the year 2017.

Chemicals and standard

Reagent grade of chemicals used for browning prevention (potassium metabisulfite) and Gembili flour characterization were the products of Merck-Indonesia and were purchased from an authorized chemical distributor in Semarang-Indonesia. Analytical grade (petroleum ether) and standard (amylose) with a purity >98 % manufactured by Merck (Germany) were used.

Gembili flour preparation

The Gembili tubers were thoroughly washed with clean tap water to remove adhering soil and other undesirable materials from the yam, and to reduce microbial growth on the final product. They were peeled and trimmed to remove defective parts, washed, and grated with semiautomatic machine to obtain thin slices (±5 mm). Then, the slices were soaked in potassium metabisulfite solution (0.075%) for 1 hour to prevent browning. After being washed with flowing water, the tuber slices were spread in a single layer on drying trays and dried in an air convection oven at 40 ºC for 3 days and were subsequently crushed in a locally fabricated crusher, milled into flour with hammer mill to obtain flour. The flour was then passed through -180 µm +250 µm sieves. Only the Gembili flour retained on the 250 µm was used in this experiment. The produced flour was stored in zip-lock polyethylene bags and kept in covered plastic containers at 20 °C for further uses.

Flour properties analysis

Color measurement

The color analysis was determined by Hunter notation system, which characterized by three color parameters as L*, a*, and b*. L* is a measure of the degree of lightness from 0 (black) to 100 (white) color. The a* value states the red-green color (red is declared from 0 to +100 and green is stated from 0 to -80). Finally, the b* value defines components on the yellow-blue axis value (0 to +70 for yellow and 0 to -70 for blue). The color of flours was measured by Konica Minolta chromameter CR 400 as suggested by **Akissoe et.al. (2003)**.

Granule microstructure

The morphology and surface of Gembili flour granules were observed by scanning electron microscope (SEM JSM-6510 LA). Prior to SEM analysis, the flour samples were freed of granule clumps by sieving through a 250 μm mesh and spread evenly on Cambridge type circular aluminum stubs with carbon electro-conductive doubled-sided adhesive tape (Electron Microscopy Science, Hatfield, PA, USA) through a thorough inspection using a stereoscopic microscope (Carl Zeiss, Stemi 2000-C, Wek Gottingen, Germany), before being coated with gold powder (10 nm) for 60 s at 50 mA under vacuum using a EMS500 sputter coater (Electron Microscopy Science, Hatfield, PA, USA) to make the sample conductive. The freed clumps and gold coated flour granules within a horizontal field width of 54.08 μm were scanned and photographed using the method and conditions as suggested by **Jayakody et al. (2007)**, except the magnification of 2000x was used in this research.

Granule crystallinity

The Prior to X-ray diffraction analysis, the Gembili flours were kept in a desiccator (at 25 ^{o}C) over saturated K_2SO_4 solution (aw = 0.98) up to sorption equilibrium (3 weeks). X-ray diffractograms were obtained with a Rigaku RPT 300 PC X-ray diffractometer (Rigaku-Denki Co., Tokyo, Japan). The crystallinity patterns of Gembili flours were recorded with X-ray diffraction at Bragg angle 2θ between 4 – 40 ^{o} using a procedure previously described by **Jayakody et al. (2007)**. The crystallinity of the flour was then quantitatively estimated following the method of **Nara and Komiya (1983)** by using a software package (Orion-version 6.0 Microcal Inc., Northampton, MA, USA).

Thermal properties

The Thermal analysis of flour Gembili was conducted by differential scanning calorimetry (DSC) using a Seiko differential scanning calorimeter (DSC 210) (Seiko Instruments Inc., Chiba, Japan) equipped with a thermal analysis data station and data recording software. Before being subjected to DSC analysis, the Gembili flour of 20% water content was prepared by addition of 11 μL deionized water using a microsyringe to 3 mg flour sample (dry basis) in the DSC pans, which were then sealed, reweighed and allowed to stand overnight at room temperature at room temperature before analysis to ensure the equilibration of sample and water. The scanning temperatures range and heating rate applied in this analysis were respectively 25 – 300 ^{o}C and 10 ^{o}C.min^{-1}, as previously used by **Jayakody et al. (2007)**. The measurements were carried out under a dynamic nitrogen atmosphere (30 mL.min^{-1}) in pierced aluminum pans to avoid condensation. In all measurements, the thermogram was recorded with an empty aluminum pan as a reference.

Swelling power and solubility

The functional properties of Gembili flour, i.e. swelling power and solubility were measured by the method of **Afoakwa et al. (2012)**. Swelling power is defined as the weight (g) of the swollen sediment per g of dry flour, while solubility is expressed as the percentage (by weight) of the flour sample that is dissolved molecularly after being heated in water at 60 ^{o}C.

Statisic analysis

All measurements were conducted in tripilicates and the data obtained were expressed as mean ±Standard deviation. Significant differences between the mean values at significance level p <0.05 were compared using Student`s test using MS Excel version 2010.

RESULTS AND DISCUSSION

Color observation

Color may attribute to the quality of foodstuffs material, such as the degree of maturity and spoiledness. Finally, the color of food also affects the consumer’s impressions. The color characteristics (L*, a*, and b*) of Gembili tuber flour are presented in Table 1. As a comparison, the same color characteristics of wheat flour are also tabulated in Table 1.

Visually, the Gembili flour is light brown in color and is even darker than the commercial wheat flour as indicated by L* value **(Ukpabi, 2010).** Lightness of flours can be affected by browning reactions, which occur during its processing, and this may have extensively affected Gembili flour and reduced its lightness. The

Table 1 Comparison of color parameters of Gembili flour and other flours.

Color parameter	This work	*D. esculenta*[a]	wheat flour[b]
L*	87.22 ±0.12	84.09 ±0.20	94.99 ±0.10
a*	1.84 ±0.00	-3.06 ±0.03	-0.78 ±0.00
b*	11.19 ±0.03	9.87 ±0.04	9.76 ±0.00

[a]Polycarp et al., (2016), [b]Ukpabi (2010).

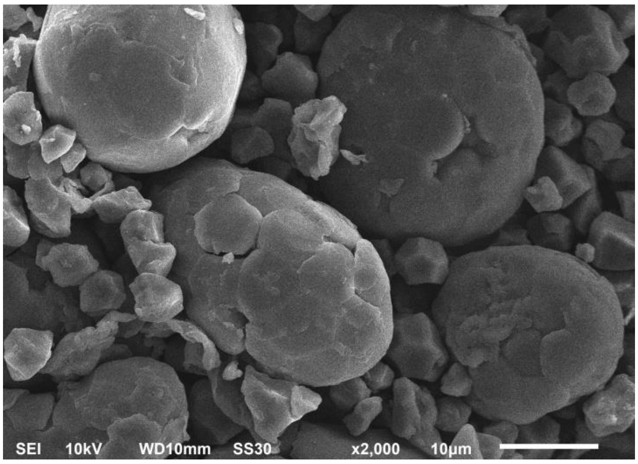

Figure 2 Scanning electron microscopy (magnification 2000×) of Gembili flour.

yellowness/blueness index (b*) value observed for Gembili flour was slightly higher than both commercial wheat flour and *D. esculenta* tuber flour grown in Ghana. This result confirms that Gembili flour appeared more yellowish than commercial wheat and *D. esculenta* tuber flours. Apart from the inherent color pigments present in yams, yellowness in yam flours has also been linked to total phenol content and the activity of polyphenoloxidase **(Akissoé et al., 2003)**. The redness/greenness index (a*) of Gembili flour was far higher than commercial wheat flour and *D. esculenta* tuber flour grown in Ghana. If the color of a food product is one of the important criteria, then the use of native Gembili flour for its manufacture should be less considered. This is because usually white flours are more preferred in various applications (as in white bread making). Theoretically, the substitution of wheat flours with Gembili flour will reduce the whiteness, but will increase the redness and yellowness of the flour composites **(Aprianita et al., 2014a)**.

Granule morphology

The scanning electron micrographs of Gembili flour is shown in Figure 2. It can be observed that the flour granules are oval in shape, which consists of polygonal or irregular form of fragments. Some fragments were scattered and were likely to be the result of the breakdown of the bigger oval structure. The surface of the granules appeared to be smooth and presented no evidence of fissures. According to observation by **Aprianita et al. (2014b)**, the smaller granule could be related to particle clusters. The average sizes of the oval structure and the polygonal fragments were 23 μm and 6 μm, respectively. With smaller starch granules size, the digestibility of Gembili flour is fairly high **(Szylit et al., 1978)**. Similarly, **Jayakody et al. (2007)** also observed that *D. esculenta* starch granules were polygonal in shape and the surfaces were smooth. The starch granules size of *D. esculenta* grown in Kukula, Java-ala, and Nattala was between 3 to 10 μm. In contrast, **Aprianita et al. (2014b)** observed a bigger average granule size of *D. alata* flour, which a high proportion of larger granules of 345 μm and a small portion of granules having 28 μm in size.

X-ray diffraction patterns

Figure 3 shows the crystallographic pattern of Gembili flour. The pattern has strongest and broad peaks centered at 17.1^o and 24.2^o, also has moderate peak at 14.9^o, and weak peaks at 5.5^o and 26^o for 2θ angles. The crystallinity of Gembili flour was around 31 ±3.7%. These characteristics indicate that Gembili flour falls in the B type starch category **(Brunnschweiler et al., 2005)**. This observation is in good agreement with **Jayakody et al. (2007)** who explained that most of tuber flours, including *D. esculenta* flours exhibit B type starch. In general,

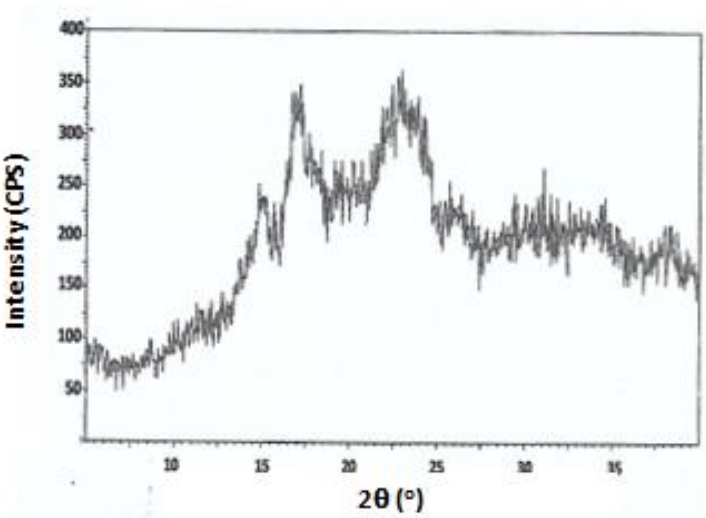

Figure 3 X-ray diffraction pattern of Gembili flour.

Table 2 The value of T_o, T_p, T_c and ΔH_{Gel} of some Dioscorea flours.

Botanical species (origins)	ΔT_o (°C)	ΔT_p (°C)	ΔT_c (°C)	ΔH_{Gel} (J.g^{-1})	Reference
D. alata (Indonesia)	62.00 ±1.72	73.90 ±0.94	81.80 ±1.12	7.40 ±0.82	**Aprianita et al. (2014b)**
D. alata (Brazil)	71.50 ±0.30	76.30 ±0.10	81.80 ±0.40	11.90 ±1.70	**Alves et al. (2002)**
D. esculenta (Indonesia)	74.34 ±0.20	79.65 ±0.50	85.83 ±0.10	9.52 ±0.80	This work
D. dumetorum (Nigeria)	NA	72.80 ±2.79	NA	NA	**Owuamanam et al. (2013)**
Low Protein Wheat	60.60 ±1.80	64.10 ±1.10	69.60 ±2.50	5.70 ±0.80	**Aprianita et al. (2014a)**
High Protein Wheat	57.80 ±1.50	63.90 ±1.10	70.30 ±1.50	5.00 ±0.90	**Aprianita et al. (2014a)**

Table 3 Swelling power and solubility of some Dioscorea flours.

Botanical species (origins)	Swelling power (g.g^{-1})	Solubility (%)	Reference
D. dumetorum (Nigeria)	2.22 ±0.01	1.93 ±0.01	**(Abiodun et al., 2014)**
D. bulbifera (Côte d'Ivoire)	2.60 ±0.01	10.20 ±0.06	**(Achyet al., 2017)**
D. alata (Indonesia)	3.00 ±0.23	6.51 ±0.02	**(Harijono et al., 2013)**
D. esculenta (Indonesia)	3.90 ±0.01	11.07 ±0.05	This work
D. hispida Dennst (Indonesia)	4.67 ±0.18	6.53 ±0.15	**(Kumoro et al., 20102)**
D. rotundata (Ghana)	13.06 ±0.22	5.88 ±0.11	**(Tortoe et al., 2017)**
American Wheat	7.33 ±0.41	6.80 ±0.42	**(Chung et al., 2010)**

starches with B-type of crystallinity, such as sweet potato, taro, arrowroot and cassava have higher digestibility compared to canna and konjac flours that have A-type of crystallinity **(Liu et al., 2007)**. The high digestibility of Gembili flour is confirmed by high solubility value as discussed in the last section of this manuscript.

Thermal properties

The disruption of solid structure can be studied by heating with the presence of small amount water through differential scanning calorimetry (DSC). In this processes, the flour sample was heated at various temperature and heating rate. The onset (T_o), peak (T_p), conclusion (T_c) gelatinization temperatures and entahlpi of gelatinization (ΔH_{Gel}) of Gembili flour obtained from DSC analysis, and those of other dioscorea flours are tabulated in Table 2.

The gelatinization temperature of Gembili flour obtained in this research is slightly higher than that of *D. alata* planted in East Java – Indonesia **(Aprianita et al., 2014b)**, but significantly higher than *D. alata* farmed in Brazil **(Alves et al., 2002)** and *D. dumetorum* grown in Nigeria **Owuamanam et al. (2013)**. A number of factors may influence gelatinization temperature, including the molecular architecture of amylopectin, the formation of lipid complexes, degrees of crystallinity, and the proportion of crystalline regions **(Aprianita et al., 2014b)**. The high initial gelatinization temperature of Gembili flour indicates that the granules were slow in swelling due to high resistant swelling of the starch granules **(Alves et al., 2002)** and therefore requires longer cooking time. Gelatinization temperature of Gembili flour was higher than that of wheat flour **(Aprianita et al. (2014a)**, which indicates a higher stability of Gembili flour compared to that of wheat flour **(Srichuwong et al., 2005)**. The Gembili flour gelatinized at a high temperature range that could bring about its application as a thickening agent in retort foods or foods that require heat stable viscosity **(Tattiyakul et al., 2006)**.

Swelling power and solubility

The functional properties of the yam flours are important since they affect the end use of the flours. Swelling power is the ability of flour to absorb water and hold it in the swollen flour granule, whereas the solubility of flour is related to the extent of leaching of amylose out of starch granules during swelling and affected by intermolecular forces and the presence of surfactants and other related substances **(Moorthy, 2002)**. Swelling and solubility depend on the characteristic of the flour granules, such as granule size, the size distribution, amylose/amylopectin ratio and mineral content **(Singh et al., 2003)**. Both properties (swelling and solubilization) contribute to the some of characterictics of food product and play important role in the determination of flour's applications. Table 3 presents the swelling power and solubility of some dioscorea flours at 60 °C.

The swelling power of Gembili flour was lower than other yam flours, such as *D. rotundata* grown in Africa **(Tortoe et al., 2017)** and D. hispida Dennst **(Kumoro et al., 20102)**, but slightly higher than *D. dumetorum* **(Abiodun et al., 2014)**, *D. bulbifera* **(Achyet al., 2017)** and *D. alata* **(Harijono et al., 2013)**. According to **Schoch and Maywald (1968**) flour classification, Gembili flour falls in the highly-restricted swelling. **Aprianita et al. (2014b)** found that the swelling powers of *D. alata* var Krimbang flours were not significantly different at temperature range from 60 to 90 °C, at which the granules maintained their integrity. Lower value of swelling power of starch of the Gembili flour might be attributed to the protein-amylose complex formation in bean isolated starch and flour **(Pomeranz, 1991)**. This characteristic is desirable for the manufacture of value-added products such as noodles and composite blends with cereals **(Garcia and Dale, 1999)**.

The solubility of Gembili flour is higher than any other dioscorea flours reported in the literature. The value is even higher than solubility of American wheat flour **(Chung et al., 2010)**. A higher value of solubility of flour signifies an improved digestibility. The high digestibility of Gembili flour might be beneficial for food preparations especially for infants and the elderly who require more readily digestible food **(Snow and O'Dea, 1981)**.

CONCLUSION

A comprehensive characterization of physicochemical, thermal and functional properties of Ubi Gembili (*Dioscorea esculenta* L.) flour has been successfully carried out. The Gembili flour was light brown incolor and was darker than commercial wheat flour. The Gembili flour granules were smooth surfaced oval structure having 23 µm average diameter, which comprised of polygonal or some clusters of irregular fragments. In accordance with typical tuber flours crystallinity, Gembili flour also exhibited B-type crystallinity with approximately 31 ±3.7% crystallinity. The gelatinization temperature of Gembili flour was high and being comparable to that of cereal flour. The enthalpy of gelatinization of Gembili flour (9.52 ±0.80 $J.g^{-1}$) was comparable to that of *D. alata*. Inherent with its crystallinity, Gembili flour exhibited low swelling power (3.90 ±0.01 $g.g^{-1}$). As expedted, the small size Gembili flour granules were highly soluble in water (11.07 ±0.05%). The low swelling power, but high solubility and gelatinization temperature suggests that Gembili flour is suitable for use as a raw material for the manufacture of bakery, cookies or noodle with hard bite and chewy texture and infant foods.

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