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Thiwul and *Gathot*, The Reviving Indonesian Traditional Fermented Foods Viewed From Microbiological, Nutritional, Historical, Cultural and Contemporary Development Perspectives

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Abstract

Fermentation has long been involved in preparation process for staple foods in many regions across the world. Two of which are *thiwul* and *gathot*, traditional Indonesian fermented staple foods. The objective of this manuscript was to observe the preparation of *thiwul* and *gathot* as viewed from microbiological (fermentation) and nutrition aspects. Furthermore, this article also elucidates the historical and cultural backgrounds as well as the contemporary developments of *thiwul* and *gathot*.

Thiwul and *gathot* are produced through five stages of fermentation. In the first fermentation, cassava is soaked and fermented involving microbes like *L. plantarum, L. fermentum, L. manihotivorans, S. cerevisiae* and etc. The second fermentation is conducted by sun-drying cassava to produce *gaplek* (dried cassava flakes), which involves xerophilic microbes. *Thiwul* is prepared by pulverizing *gaplek* and steaming its flour. Meanwhile, *gathotan* (unpulverized *gaplek*) subsequently undergoes the third fermentation before the desiccation (4th fermentation) in which *Aspergillus nomius*, *Fusarium oxysporum*, *Aspergillus niger* and *Rhizopus oryzae* dominate. Lastly, the *gathotan* is stored and fermented for a certain period before being prepared as *gathot*. In the terms of nutrition, the fermentation of *thiwul* and *gathot* provides nutrients such as dietary simpler carbohydrates, prebiotic, probiotic, antioxidant, and digestive enzymes. Fermentation also reduces the concentration of cyanide, a naturally occurring anti-nutrient in cassava tubers, and heavy metals.

Historically, *thiwul* and *gathot* were created and consumed by lower-class individuals as a solution to famine. These foods have also long been served at some traditional ceremonies in rural areas in Java like *selametan*, *nyadran* and *den baguse*. Although the consumption of these foods ever experienced a decrease due to the improvement of Indonesian economic condition, they have gradually gained a popularity because of “back to nature” lifestyle, nostalgic feelings and the rise of Indonesian tourism which emerges a number of innovations including multi-flavor *thiwul ayu*, instant *thiwul*, instant *gathot*, *thiwul goreng* and etc.

Keywords : *thiwul*, *gathot*, *gaplek*, fermented foods, nutrition, Indonesian traditional food, microbes.

Introduction

Staple foods play a pivotal function in human diet by providing a significant amount of carbohydrates (in various types) as the primary source of energy (Durmelat., 2015; Zocchi *et al*., 2022). Typically, these foods are usually served alongside proteins, vegetables, fruits and beverages; creating an ideal daily meal composition as discovered in nearly entire civilizations across regions in the world (Zocchi *et al*., 2022). Instances of staple foods from different geographical areas in the world include rice, wheat, cassava, maize and potatoes which have long processed and consumed to meet the basic nutritional requirement. The processing methods of preparing these staple foods have long been shaped by unique histories, cultural and gastronomical backgrounds; creating distinctive physical and nutritional characteristics (Durmelat., 2015; Waisundara., 2018; Zocchi *et al*., 2022). However, staple foods, sometimes, also contain particular anti-nutrients which can negatively impact the human health. Thus, additional processing methods are required to decrease the concentration of these anti-nutrients (Waisundara., 2018).

Rice has been cultivated and consumed in Indonesia for over 5000 years since its first introduction, making the country as one of top rice producers and consumers in the World (Rahman., 2021; FAO., 2023a). Within addition to rice, Indonesia is also the seventh largest producer of cassava globally with the level of production had approximately reached 13.5 million metric tonnes as of 2022 (Rahman., 2021; FAO., 2023b). Cassava has long been consumed as a staple food in some areas in Indonesia, shaping particular local identities for centuries since its arrival from Central America via the Columbian interchange in 17th century (Falade and Akingbala., 2010; Rahman., 2021). Two of cassava-based dishes are *thiwul* and *gathot* which are native to karstic regions of Java Island and historio-gastronomically associated with lower income community (Rahman., 2021). However, the waves of "back to nature" movement, the feeling of nostalgic and also the resurrection of Indonesian tourism industry in the last decades have consequently shifted the past perception of these foods (Putra *et al*., 2021; Istiasih., 2023; Palupi *et al*., 2024). Those activities have adversely been reviving and improving the value of *thiwul* and *gathot* which were, in a certain period, abandoned, especially after the rise of Indonesian economical condition in the mid of 20th century onwards (Rahman., 2021).

Meanwhile, the preparation of Indonesian traditional foods often involves various processing methods, one of which is fermentation process. Many species of indigenous microbes have been spontaneously and even purposively inoculated during the fermentation of Indonesian traditional foods (Nuraida., 2015; Anggadhania *et al*., 2023). Fermentation facilitates the production of particular nutrients which are meritorious for the health, those of which are simpler dietary carbohydrates and antioxidants (Purwandari *et al*., 2014b). Carbohydrates like α-glucans, β-glucans, iso-α-glucans are examples of functional carbohydrate which possesses specific functions, one of which is assisting in lowering blood sugars; thus, those carbohydrates are amiable for people suffering diabetes (Nami *et al*., 2021; Karkar *et al*., 2024). Meanwhile, antioxidants play an essential function in capturing free radicals in which this mechanism can consequently help in preventing people from various types of cancer (Prastowo *et al*., 2023). Furthermore, fermentation also provides living bacteria which can colonize and propagate inside the intestine, assisting the digestive system in degrading foods (Prastowo *et al*., 2023; Karkar *et al*., 2024).

This manuscript is a literature review which explores each stage of fermentation process involved in the production of *thiwul* and *gathot*. The roles of microbes during the fermentation are elucidated and documented from a number of research articles, especially microbial activities in producing particular nutrients e.g. functional carbohydrates, antioxidants, amino acids and etc. This article further discusses on other aspects of those foods as viewed from historical and cultural perspectives, as well as, the recent innovations influenced by the dynamics of Indonesian tourism industry.

History of *Thiwul* and *Gathot*

The emergence of *Thiwul* and *Gathot* is closely related to the historical cultivation of cassava in Indonesia, especially in Java. It was commenced with Portuguese and Spanish merchants who introduced this tropical vegetation from South America to the Indonesian archipelago in 16th century A.D (Abdurrachman., 2008; Waisundara., 2018; Rahman., 2021). These starch-rich tubers were initially cultivated in Moluccan islands by those Iberian nations, especially close to their trading posts, which was probably consumed as an alternative staple food when the stock of wheat from Europe became extremely limited (Abdurrachman., 2008; Rahman., 2021). They probably utilized the flour or ground cassava to make a flatbread-like dish which is similar to the modern *Casabe de Yuca*, a popular South American traditional flatbread, inspired from the food preparation of *Arawak* ethnic group (Waisundara., 2018).

During Dutch East India Company (VOC) colonial activities in Indonesia (17th until the last 18th century A.D), the crop was subsequently introduced to the main island of the region, Java Island, initially as an ornamental vegetation. The Dutch and even, the native Javanese, were not interested in consuming cassava in those periods (Marwanti *et al*., 2024). In 1799, the bankruptcy of the VOC insisted the Dutch government to annex entire colonies in the region from the company. From the beginning 18th until the first quartile of 20th century A.D., the initial territories were expanded to include most of the recent Indonesian area which often triggered enormous conflicts (wars) with local sovereignties. Java War (1825 – 1830), Minangkabau War (1803 – 1837) and Aceh War (1873 – 1904) were examples of the famous insurgency contended by locals against the Dutch colonial government which further resulted in a financially detrimental condition of the Netherlands. Furthermore, this situation was exacerbated by the Belgian revolution in Europe (1830 – 1831) in which Dutch government also had to face the Belgian rebels, subsequently resulting in the kingdom of Belgium to be a separated entity from the former United Kingdom of the Netherlands (Poespaningrat, 2008).

The deficit financial condition emphasized the Dutch colonial government to implement the colossal cultivation system (*cultuurstelsel*). The export-oriented agricultural commodities which gained the international market interests such as rubber, tea, sugarcane, coffee, cacao, cassava, tobacco, corn, cotton and etc were massively cultivated in regions across Indonesia (Poespaningrat, 2008; Rahman., 2021). In this era, the initial cultivation of cassava as an agricultural commodity was started in Java (especially, initially cultivated in one of regions in Eastern Java in 1857) as the global demand of starch dramatically increased due to the massive textile and paper industrialization (Rahman., 2021). It was reported that the cassava cultivation was only conducted in some areas in Java and Sumatra in 1875, especially in limited private and government-owned farms. Later, the locals commenced to gradually cultivate cassava in the areas closed to their rice fields, as an alternative of staple food. The local inhabitants usually consider cassava as the “underground rice” which was usually consumed when the production of rice was quite atrocious. Not only cultivated in fertile areas, but cassava was also started to be cultivated in semi-arid karst regions in southern Java (Pacitan, Wonogiri, Gunung Kidul, Trenggalek and Ponorogo regencies), in which the tubers have a slightly different characteristic in comparison to the common cassava tubbers (Rahman., 2021; Marwanti *et al*., 2024). In the Japanese occupation era (1942 – 1945), the military-based government decreed the entire agricultural products (notably rice) had to be allocated for the military interests, especially as a food logistic for Japanese troops during World War II. As a result, the scarcity of rice as the main staple food for native inhabitants effectuated a famine and poverty in the region (Rahman., 2021). To overcome those problems, thanks to the ingenuity of native Javanese people, the “underground rice” (cassava) was exploited and exerted as the main staple food to substitute the rice. Many cassava-based dishes were created in this period. In the karst regions of southern Java, people have developed a long unique tradition related to cassava processing traced back to Japanese occupation era. The tuber processing is quite simple (Rahman., 2021; Ketaren., 2021). Flakes of cassava tuber are traditionally sun-dried to produce a *gaplek* (dried cassava flakes) which is later ground into flour (Rahman., 2021; Marwanti *et al*., 2024). Furthermore, from the *gaplek* basis, *thiwul* and *gathot* are traditionally created. The origin of the word “*thiwul”* is etymologically still innominate. The closest Javanese word to that word is “*thowel*”, literally meaning “to grab small things”. Hypothetically, the cooking process of *thiwul* requires the manual granulation process of rehydrated sun-dried cassava flour; involving mixing, grabbing and rolling activities by hands to create small pellets. The word also has a close root to the words “*diawul – awul*” which means “to vigorously mix”, indicating the similar process to the aforementioned. Meanwhile, the word ”*gathot*” is etymologically an abbreviation from *GAgal* (failed) and *TOTal* (totally), or “totally failed”. Probably, the food was historically created in Japanese occupation era (1942 – 1945), when Javanese people were totally failed in discovering the proper staple food (rice). Another etymological reason behind the food’s name is due to the food's blackish appearance which is a reminiscence of *Raden Gathotkaca*, a legendary figure with dark (black) skin in the Javanese leather-based puppet shadow show (*wayang kulit*) (Sastrapradja., 2012; Rahman., 2021). In the Indonesian independence revolution era (1945 - 1949), the new country struggled a series of wars which disabled the people to have normal daily activities. Part of people (including farmers) had to travel in a distance to other regions and became refugees, disabling the cultivation of rice in several regions in the country. Since the rice was arduous to obtain, people re-utilized cassava (including prepared as *thiwul* and *gathot*) as a staple food as the cassava can ubiquitously grow and does not require particular treatments in cultivation (such as continue irrigation, fertilizing, and etc). Even, not only a staple food for the common people, both dishes (*thiwul* and *gathot*) played an instrumental function as a survival food for the Indonesian freedom fighters in that period. About 15 years afterwards, especially in the guided democratic era (1959 – 1966) of the old order (Soekarno's presidency), the republic country experienced a severe hyper-inflation (up to more than 500%) which decreased the purchasing power of Indonesian people. The price of goods (including rice) was unreasonably exorbitant. The condition insisted destitute people on re-consuming the cassava and its derivative products (including *thiwul* and *gathot*). As Indonesia subsequently entered the new order era (1966 – 1998), the country experienced the economic stability which enabled Indonesian people effortless to obtain the proper daily foods (including rice). As a result, *thiwul* and *gathot* were gradually neglected (Rahman., 2021).

Fermentation Process of *Thiwul* and *Gathot*

Fermentation of *Gaplek* (Sun-Dried Cassava Tubers)

As aforementioned, *gaplek* is the basic ingredients in the *thiwul* and *gathot* production in which the entire production process of those is summarized in figure 1. The production process is commenced with the slicing of peeled cassava tubers (Fig. 1 and 2A). The sliced tubers are subsequently fermented by soaking them in the water for nearly two up to four days in the closed chambers (Fig. 1, 2B and 2C) (Damayanti *et al*., 2020; Mauroh *et al*., 2023). In the first fermentation process (soaking process), the indigenous microbes like *Lactobacillus plantarum*, *Lactobacillus fermentum*, *Lactobacillus manihotivorans*, *Saccharomyces cerevisiae*, *Candida ethanolica* and etc naturally growing on the surface of cassava tubers gradually propagate by utilizing carbohydrates from the raw material (table 1) (Lacerda *et al*., 2005; Astriani *et al*., 2018; Harmayani *et al*., 2017; Damayanti *et al*., 2021, Nurhayati *et al*., 2023; Mauroh *et al*., 2023). Here, this fermentation process is largely dominated by lactic acid bacterial and yeast species as shown in Table 1 (Lacerda *et al*., 2005; Astriani *et al*., 2018; Damayanti *et al*., 2021; Nurhayati *et al*., 2023; Mauroh *et al*., 2023). The secretion of amylolytic (α-amylase [EC. 3.2.1.1], β-amylase [EC. 3.2.1.2], pullulanase [EC 3.2.1.41] and amyloglucosidase [EC. 3.2.1.3]) and cellulolytic (endo-cellulase [EC 3.2.1.4], exo-cellulase [EC 3.2.1.91] and β-glucosidase [EC 3.2.1.21]) enzymes by microbes can further assist in the starch and cellulose degradation, respectively, into simpler carbohydrates (Table 2) (Hastuti *et al*., 2014; Chalisya *et al*., 2020; Damayanti *et al*., 2021). Cellulolytic (endo-cellulase, exo-cellulase and β-glucosidase) enzymes degrade cassava cellulose and hemicellulose into simpler β-glucans (cellodextrin, cellopentose, cellotetraose, cellotriose and etc), cellobiose and glucose, thus also facilitating the extraction of starch from cells (Table 2) (Ogunremi and Sanni, 2011; Hastuti *et al*., 2014; Hastuti *et al*., 2015; Chalisya *et al*., 2020; Sharma *et al*., 2020). In the same period, amylolytic (α-amylase, β-amylase, and amyloglucosidase) enzymes further modify the structure of starch by producing a number of linear and branched oligosaccharides (dextran, maltodextrin, isomaltodextrin, maltopentose, maltotetraose, maltotriose, isomaltose and etc), disaccharides (maltose and isomaltose) and monosaccharide (glucose) (Hastuti *et al*., 2014; Hastuti *et al*., 2015; Chalisya *et al*., 2020; Sharma *et al*., 2020; Damayanti *et al*., 2021; Mauroh *et al*., 2023). Pullulanase, meanwhile, acts as a debranching enzyme that degrades pullulan (degrading α-1,6 and α-1,4 linkages for pullulanase type I and II, respectively), producing maltooligosaccharides and maltose (Chalisya *et al*., 2020; Sharma *et al*., 2020; Naik *et al*., 2023). Proteases are also released which facilitate the modification of cassava proteins into amino acids and peptides. Additionally, the presence of proteases assists in the starch extraction by degrading amyloplasts (Chalisya *et al*., 2020; Kusuma *et al*., 2021).

Some lactic acid bacterial species like *Brevibacillus brevis, Lactobacillus plantarum, and Lactobacillus casei* experience a homofermentative metabolism in which the bacteria anaerobically metabolize monosaccharide (glucose) via glycolysis and lactic acid fermentation pathways inside the cells and produce lactic acid and ATP molecules for the cells' energy (Table 2) (Astriani *et al*., 2018; Damayanti *et al*., 2021; Borowska *et al*., 2023; Mauroh *et al*., 2023). Meanwhile, other lactic acid bacterial species like *Lactobacillus fermentum, Bifidobacteria*.sp *and Lactobacillus brevis* experience heterofermentative metabolism (via glycolysis and phosphoketolase pathways) in which glucose molecules are metabolized into, not only lactic acid, but substances including ethanol, acetic acid and other organic acids as well as ATP are also released (Table 2) (Damayanti *et al.*, 2021; Nurhayati *et al.*, 2023). Furthermore, in anaerobic condition, yeast like *Saccharomyces cerevisiae*, *Saccharomyces boulardii* and *Candida ethanolica* play a crucial role in the production of ethanol via glycolysis and ethanol fermentation pathways (Table 2) (Lacerda *et al.*, 2005; Martínez-Miranda *et al.*, 2022; Mauroh *et al.*, 2023). During fermentation, pH drops up to 3 – 4.5 in which the solution becomes acidic and slightly alcoholic due to the microbial activities (Fig. 2C) (Damayanti *et al.*, 2021; Mauroh *et al.*, 2023). Cassava exhibits a fair concentration of cyanide, an anti-nutrient naturally contained in the root, which can be harmful for the human health. Several species of microbes like *Lactobacillus plantarum*, *Pediococcus pentosaceus*, *Lactobacillus fermentum*, *Pichia kudriavzevii* and *Pichia burtonii* are detected to secrete linamarase, an enzyme that facilitate the degradation of linamarin (cyanide-bound carbohydrates) during the cassava fermentation, releasing a soluble cyanide (Nwokoro., 2016; Banwo *et al.*, 2023). Some microbes (*Lactobacillus plantarum* and *Weissella cibaria*) also play a pivotal function in absorbing toxic heavy metals from cassava and utilize those metals as a cofactor for their metabolic enzymes (Ojekunle *et al.*, 2017). Later on, the solution is discarded and cassava flakes are washed using a flowing water to reduce acidity (Damayanti *et al.*, 2021; Mauroh *et al.*, 2023).

After washing, the cassava flakes are subsequently sun-dried for nearly 2 weeks and experience the second fermentation process (Fig. 1 and 2D). In the early periods of the second fermentation process, the lactic acid bacteria and yeast still survive, grow and secrete enzymes (table 1) (Harmayani *et al.*, 2017). As the fermentation condition turns to be more aerobic, the facultative anaerobic microbial cells tend to drastically propagate, rather than producing metabolites (ethanol, lactic acid, acetic acid and other organic acid). These microbes aerobically metabolize glucose through glycolysis and krebs-cycle pathways, producing more ATP molecules for the cell growth (Prastowo *et al*., 2023). Meanwhile, the growth of obligate microbes tends to reduce in this condition. On the other hand, at the similar period, wild-type fungal and bacterial species from the environment such as *Bacillus licheniformis, Bacillus brevis, Bacillus cereus, Lasiodiplodia theobromae, Rhizopus oryzae* and *Fusarium oxysporum* start growing on the surface of sun-dried cassava flakes (Table 1) (Lacerda *et al*., 2005; Purwandari *et al*., 2014a; Astriani *et al*., 2018; Damayanti *et al*., 2021; Hallis et al., 2021; Mauroh *et al*., 2023). These fungal and bacterial cells also secrete their indigenous cellulolytic and amylolytic enzymes during the sun-drying process (Table 2) (Chalisya *et al*., 2020). The diversity of fungal and bacterial species is determined by the climate and location in which cassava is usually processed. As the sun drying process proceeds, only xerophilic microbes such as *Aspergillus nomius*, *Fusarium oxysporum*, and *Rhizopus oryzae* among those microbial communities can survive (Table 1) (Ogunremi *et al*., 2015; Harmayani *et al*., 2017; Akroman *et al*., 2019; Damayanti *et al*., 2021; Hallis et al., 2021; Mauroh *et al*., 2023; Wahyuni *et al*., 2023). Meanwhile, microbes which are not resistant to drought prolong their survival fate by forming spores, further assembling into new cells in the appropriate environment (Oguntoyinbo., 2007). The rate of the enzymatic reactions is quite rapid at the beginning of fermentation process in the presence of water. As the flakes are desiccated, enzymatic hydrolysis reactions subsequently become slower (Harmayani *et al*., 2017; Akroman *et al*., 2019; Damayanti *et al*., 2021; Wahyuni *et al*., 2023). The different composition of microbes growing on the surface of cassava flakes results in the different physical characters of cassava flakes. Even, both fragile and rubbery structures are frequently discovered in a single portion of cassava flake (Fig. 1 and 2E) (Harmayani *et al*., 2017; Defri *et al*., 2022).

Preparation of *Thiwul*

The fragile structure of dried cassava flakes is manually pulverized to traditionally produce *gaplek* (sun-dried cassava flake) flour, leaving the hard and rubbery flakes (*gathotan*) (Fig. 1 and 2F). The composition of carbohydrates (amylose, amylopectin, maltodextrin, iso-maltodextrin, maltose, and glucose), metabolites mixture (lactic acid, ethanol, acetic acid and other acids), peptides and also microbial spores contribute to a slightly yellowish color, coarse and glutinous characteristics of the *gaplek* flour, as compared to cassava starch (Fig. 1 and 2G) (Chalisya *et al*., 2020; Defri *et al*., 2022). Fermentation also naturally improves protein content in the *gaplek* flour as microbial cells have long been identical with a single cell protein. In the structural level, microbial cell and its organelles are mostly constructed by linkages of protein (Defri *et al*., 2022; Rubi and Minhaj., 2024; Arifah *et al*., 2024). Thus, the propagation of microbes during the fermentation process may increase the protein concentration, including in the cassava flakes fermentation. Meanwhile, the protein degradation by microbes improves antioxidant activity since several amino acids exhibit antioxidative activity (da Silva *et al*., 2022).

As the amounts of water are sprinkled over, the sun-dried cassava flour is later homogenously mixed and rolled up into small granules (Fig. 1 and 2H). The preparation of *thiwul* is conducted by steaming the dried-cassava flour granules until the consistency resembles glutinous rice (Defri *et al*., 2022). It is suggested that the ratio of linear chain (amylose and maltodextrin) to branched chain (amylopectin and iso-maltodextrin) carbohydrates in sun-dried cassava flour plays a pivotal role in determining the glutinosity level of *thiwul*. As the granules are cooked, the crystalline structure of linear and branched carbohydrates loses and experiences a gelatinization, holding high amount of moisture to create viscous structure. The structure of linear chain and the linear part of branched chain carbohydrates subsequently retrogrades to the crystalline structure as the granules are completely cooled, fabricating a glutinous structure of *thiwul* (Fig. 1, 2I and 2J) (Defri *et al*., 2022). On the other hand, the spores of living microbes are probably unintentionally encapsulated by carbohydrates during the cooking of granules (Nami *et al*., 2021; Fan *et al*., 2021; Karkar *et al*., 2024). Furthermore, the appearance and preparation techniques of *thiwul* reminisce about the north African *couscous* as prepared from semolina wheat flour. However, the historical interconnection between both dishes is still unidentified (Durmelat., 2015; Zocchi *et al*., 2022). *Thiwul* tastes a slightly sweeter than the common rice due to the presence of glucose as a ramification of fermentation process (Damayanti *et al*., 2021; Defri *et al*., 2022; Mauroh *et al*., 2023).

Fermentation of *Gathot*

The unpulverized *gaplek* flakes (hard and rubbery flakes) or usually recognized as *gathotan* are usually submerged in the water for 2 - 3 days to re-hydrate (the third fermentation) (Fig. 1, 2K and 2L) (Purwandari *et al*., 2014a). As the soaking process turns the fermentation condition to become more anaerobic, the *gathotan* experiences the similar fermentation process as that of the first fermentation (the fermentation of sliced cassava), producing metabolites (acids, alcohol and other metabolites), simpler carbohydrates and proteins as well as reviving the dormant microbes such as *Lactobacillus plantarum, Weissella cibaria, Saccharomycopsis fibuligera* and *Saccharomyces cerevisiae* (Table 1) (Purwandari *et al*., 2014b; Astriani *et al*., 2018; Damayanti et al., 2021; Hallis *et al*., 2021; Nurhayati et al., 2023; Mauroh *et al*., 2023). As the fragile structures of flakes are partially extracted during the pulverization, the process leaves hard and rubbery flakes, dominated by β-glucans, and a small portion of α-glucans. Those carbohydrates are further enzymatically hydrolyzed to produce simpler β and α glucans during the fermentation (Table 2). As a reverberation, the third fermentation process produces a mushroom-like chewy structure of cassava flakes (Purwandari *et al*., 2014b; Harmayani *et al*., 2017; Chalisya *et al*., 2020). Furthermore, the chewy cassava flakes undergo the fourth fermentation (sun-drying process) for approximately 5 days in which the fermentation process is quite similar to that of the second fermentation, allowing the xerophilic microbes like *Aspergillus nomius, Fusarium oxysporum, Aspergillus niger* and *Rhizopus oryzae* to continues the duties to produce simpler β and α glucans as well as glucose (Table 1 and 2; Fig. 1 and 2M) (Hallis *et al*., 2021; Nurhayati *et al*., 2023; Mauroh *et al*., 2023). According to the local knowledge, the best period for producing *gathot* is the wet season since days in that season comprise several rainy and another sunny hours in the single day (Purwandari *et al*., 2014a; Harmayani *et al*., 2017). Production of *gathot* during the wet season takes a relatively longer time as compared to that of in the dry season. The rain may naturally disperse the diverse wild microbial spores onto the sun-dried *gathotan*. The blackish or even vibrant colors of *gathotan* proof the diversity of wild-type microbes (like *Aspergillus nomius, Fusarium oxysporum*, *Aspergillus niger* and *Rhizopus oryzae*) involved in the *gathot* fermentation (Harmayani *et al*., 2017; Hallis *et al*., 2021; Nurhayati *et al*., 2023; Mauroh *et al*., 2023). On the other hand, metabolites produced from the third fermentation can be a selective factor for wild microbes to propagate on the sun-dried *gathotan* (Astriani *et al*., 2018). After drying, the dried *gathotan* is stored and experiences the fifth fermentation (Fig. 1 and 2N) involving many species of microbes as tabulated in Table 1 and 2, producing simpler carbohydrates (including glucose). As a consequence, a series of those processes contribute to increase the sweetness level of *gathot*, which even tastes slightly sweeter as compared to *thiwul* and other cassava-based processing products (Purwandari *et al*., 2014a; Harmayani *et al*., 2017). This food is traditionally prepared by steaming the *gathotan* (Fig. 1 and 2O). In addition, spores of microbes involved in *gathot* fermentation are also trapped and encapsulated by a gelatinization-retrogradation mechanism of carbohydrates during cooking (Nami *et al*., 2021; Fan *et al*., 2021; Karkar *et al*., 2024). In optional, the palm sugar is frequently incorporated prior to the steaming, to sweeten the food (Fig. 1 and 2P) (Rahman., 2021).

***Thiwul* and *Gathot* Nutrition**

Thiwul and *gathot* are rich in many types of simpler α-glucans (maltodextrins, iso-maltodextrins), β-glucans (cello-dextrins), disaccharides (maltose, iso-maltose and cellobiose) and glucose which nutritionally have particular functions (Montagnac *et al*., 2009; Harmayani *et al*., 2017; Damayanti *et al*., 2021). In *thiwul*, for instance, particular proportion of maltodextrins and iso-maltodextrins determines retrogradation level of carbohydrate which further influences its glutinosity level and digestibility (Lestari *et al*., 2013; Defri *et al*., 2022). The carbohydrates' crystalline structure can resist these substances to be easily degraded by gut microbes, making *thiwul* to be the future candidate of resistant starch. Although the food tastes slightly sweeter and shares 1.13 times higher calories due to the glucose content, *thiwul* contains 4.25 times higher amount of dietary fiber (as compared to rice) (Ambarsari *et al*., 2022). Resistant starch, in this case retrograded starch, is categorized as dietary fiber since the starch possesses similar physiological properties as natural fiber, inducing peristaltic movements in the intestine. To prevent from the consumption of high calorie, it is suggested to consume *thiwul* in combination with low calorie dishes like tempeh, vegetables, nuts, and etc (Lestari *et al*., 2013; Defri *et al*., 2022).

Another dietary fiber is β-glucans (simpler β-glucans), largely dominating the carbohydrate content in *gathot*. Simpler β-glucans act as a prebiotic which provides fermentable sugars for gut microbes to propagate, assisting the digestive system in degrading foods (Harmayani *et al*., 2017; Kusuma *et al*., 2022). Furthermore, the fermentation of β-glucans in colon activates mechanisms related to cholesterol and glucose metabolisms, as well as, the immune system activation (Kusuma *et al*., 2022). Moreover, β-glucans can also induce a peristaltic force to propel the feces, providing a valuable physicochemical assistance for people associated with constipation in digesting foods. The enzymatic degradation products of proteins can also enrich the nutrition of both products (*thiwul* and *gathot*) with the anti-oxidative power which can further prevent cancer since being able in scavenging free radicals (da Silva *et al*., 2022).

The foods (*thiwul* and *gathot*) also provide the trace of living microorganism in the form of encapsulated microbial spores, as aforementioned. As the dishes are consumed, the enveloped spores are chemically unveiled by gastric acid to deliberate the spores. As spores enter and discover the appropriate environment in intestine, they will re-develop and multiply as new microbial cells (Prastowo *et al*., 2023; Karkar *et al*., 2024; Nugroho *et al*., 2024). These microbes (probiotics) secrete enzymes like amylases, lipases and proteases which help the digestive system in degrading food materials. The growth of these probiotics can also repress the growth of foodborne bacteria in gut, creating a healthy digestive system and improving the human's health in overall (Prastowo *et al*., 2023). Furthermore, the dead and decayed cells of microbes, amino acids, free fatty acids as well as numerous enzymes deliberated from those inactive cells can still demonstrate significant activities in empowering the work of digestive system. The materials are scientifically recognized as postbiotics, recently becoming a subject of concern in food science due to their functional superiority (Nugroho *et al*., 2024).

Serving Traditions and Contemporary Developments

Although agricultural system in Indonesia experiences a drastic improvement (including irrigation system), especially from Indonesian new order (1966) to nowadays, which enables the farmers to cultivate rice in a larger quantity, the foods like *thiwul* and *gathot* are still traditionally served as a staple food in several traditional ceremonies (Rahman., 2021). In some karstic regions in Java, for instance, traditional ceremonies such as *selamatan* and *nyadran* frequently prepare both dishes. *Selamatan* ceremony, coming from the word of ”*salam*” (an Arabic word for “peace”) is a syncretic tradition of Islamic and Javanese origins which is organized to celebrate special events such as birthday, marriage, death, house relocation and etc. In this feast, the organizing hosts usually prepare and serve foods such as staples, salads, fruits, snacks and meats for the invitees. This ceremony symbolizes a unity among Javanese in asking for the peace to come into their life. In this traditional feast, especially in Gunung Kidul and Wonogiri regencies, *thiwul* and *gathot* are usually served as both; a staple food and snack (Fig. 3A) (Muqqodam and Maghfiroh., 2019, Rahman., 2021). Meanwhile, *thiwul* and *gathot* are also often served in *Nyadran* ceremony in Gunung Kidul and Wonogiri regencies, a communal feast that is annually organized to honor the dead ancestors (Fig. 3A). People usually gather in an area close to a graveyard, praying for their ancestors and ended up by a communal eating feast. The name of this tradition comes from a Sanskrit word of “*sraddha*” (literally meaning “to ennoble”) and has a long historical Hindu-Buddhism origin with some Islamic values (Rahman., 2021; Mazid *et al*., 2024).

Interestingly, both dishes are also associated with a pest eviction ritual. In Gunung Kidul regency, locals believe that the pests, notably the mice, which usually devastate their crops are mythologically considered as an incarnation of soldiers of *Nyi Roro Kidul*, a Javanese legendary ruling figure of the southern sea (Indian Ocean). They believe, the notion of serving foods (mainly *thiwul* and *gathot*) at several corners of the agricultural area could be a gravitational attraction for the mice (the mythical soldiers of *Nyi Roro Kidul*) (Fig. 3A). As a ramification, this traditional ritual could further prevent the farm from the brutal mice invasions. This local wisdom-based ritual is usually organized in the cultivation period and popularly recognized as the "*Den Baguse*" ritual. The words of "*Den Baguse*" literally mean "the noble ones", dedicated for the soldiers of *Nyi Roro Kidul* (the mice) (Nugraha., 2022).

Waves of promotion in the area of tourism has massively been being orchestrated by the government in last decades to attract global communities to visit Indonesia. The program has consequently emphasized tourism and hospitality industries in the country, including culinary industries. *Thiwul* and *gathot* which are identical with an inferiority have been being highlighted as a specialty in some promotional digital media like Instagram, WhatsApp and Youtube, designated to exhibit an amalgamation of history, cultural, nutrition and scrumptiousness superiority and uniqueness (Nopita *et al*., 2023). *Thiwul* is usually served as a staple food for savory dishes and sweetened snack. In Gunung Kidul regency, for instance, *thiwul* is often traditionally served with fried chicken, spicy vegetables and sambal (chili sauce) (Fig. 3B) (Soenardi., 2018). The dish is currently often discovered in restaurants and food vendors in tourism resorts (beaches, lagoons, mountains, karstic caves and etc) in the area, enhancing the sense of vacation with cultural touches (Nopita *et al*., 2023; Marwanti *et al*., 2024). Meanwhile, in Pacitan regency, locals usually prepare *thiwul goreng* in which *thiwul* is cooked with a technique similar to that of Indonesian *nasi goreng* (fried rice) in which *thiwul* is stir-fried with spices, eggs, shredded chicken meat and vegetables, offering a unique experience for people who visit the region (Fig. 3D) (Sumodiharjo., 2022). On the contrary, to create *thiwul*-based sweets, a large quantity of palm sugar is incorporated during the re-hydration and granulation processes of sun-dried cassava (*gaplek*) flour. The sweets are usually served with a grated coconut flesh topping. The dish is popularly known as *thiwul ayu* which literally means the “beautiful *thiwul*”, metaphorically demonstrating that the dish tends to taste sweet (Fig. 3E). Nowadays, *thiwul ayu* is not only traditionally sold in original version, but the dish is also produced using various versions of modern flavoring agents like green tea, pandan, strawberry, chocolate, cheese and etc (Defri *et al*., 2022; Nopita *et al*., 2023). Meanwhile, *gathot* is traditionally served as a sweet snack and garnished with a grated coconut flesh topping (Fig. 3C) (Rahman., 2021). *Thiwul* along with *gathot* are also sold in restaurants, local markets and shops, in the form of dried version or popularly recognized as “*thiwul* and *gathot* instant” (Fig. 3F, 3G and 3H). Costumer can purchase these products and cook them at home following the manuals attached on the products (Alfian., 2019).

Conclusions

Thiwul and *gathot* are produced through a five-stage fermentation process that involves various indigenous microorganisms, primarily lactic acid bacteria and fungi. This fermentation breaks down complex carbohydrates into simpler, more digestible forms. Additionally, the process enriches these foods with beneficial nutrients such as prebiotics, probiotics, antioxidants, and digestive enzymes, while also reducing harmful substances like cyanide and heavy metals in cassava, enhancing its overall nutritional value. Historically, *thiwul* and *gathot* were developed as survival foods during times of famine. However, they have experienced a resurgence in popularity after overwhelmed due to Indonesian economic growth. Traditionally served in both savory and sweet variations, modern food technology has further expanded the diversity of *thiwul* and *gathot*, making them iconic dishes that contribute to the growth of Indonesian tourism industry.

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