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MINI REVIEW

A review of the applications of different drying methods of banana flour preparation

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Abstract

The perishable nature of bananas, which is highly susceptible to physical, mechanical, and physiological damage, could result in significant postharvest loss and waste. Drying is extensively used to preserve the storage life of agricultural products, thereby allowing their whole-year availability. It also assists in the development of value-added products, such as banana flour. However, despite its ability to preserve fresh materials, drying can also alter the chemical, nutritional, and functional properties of the resultant products. Hence, the selection of the most suitable method and operating parameters is critical to minimize alterations in product quality during drying. This article aimed to review and compare various drying methods applied in previous research on banana flour preparation. In general, sun-, solar-, and oven-dried banana flour often present low quality, whereas freeze-dried banana flour presents good quality. However, the results vary according to the operating parameters employed in each study.

1. Introduction

Banana (*Musa* spp.) is the second most widely grown cultivar worldwide and can be found in approximately 130 tropical countries (Falade and Oyeyinka, 2014; Fadimu *et al*., 2018), indeed, it is categorized as one of the most important global crops after rice, wheat, and maize (Khoozani *et al*., 2019). Unfortunately, the perishable nature of this climacteric fruit (Fikadu *et al*., 2016; Olawuni *et al*., 2018) could result in substantial postharvest waste and loss (Prabha and Kumar, 2013; Sunitha *et al*., 2017).

The effectiveness of drying treatment to prolong the stability of fruits during storage has long been recognized (Babu *et al*., 2018; Calín-Sánchez *et al*., 2020). Besides preservation, drying could also promote the development of value-added products, such as flour from dried bananas, with similar or improved quality (Berk, 2009). Banana flour is a major product that could be obtained from the drying treatment of bananas (Hasmadi *et al*., 2021).

Drying or dehydration refers to the process of moisture removal from food materials, thereby producing dried products with reduced water activity (Calín-Sánchez *et al*., 2020). According to Rahman (2007), the drying process can be grouped according to the moisture removal approach into thermal drying, osmotic dehydration, and chemical dewatering. Thermal drying, the most widely used drying method currently available, involves heat and mass transfer (Maisnam *et al*., 2017). During the drying process, heat transfer may occur through conduction, convection, and radiation (Sangamithra *et al*., 2014). Mass transfer, which refers to the removal of moisture, could reduce the availability of water for chemical, microbial, and enzymatic reactions. Inhibition of these undesirable reactions could reduce the risk of product deterioration (Ahmed *et al*., 2013; Guiné, 2018). Drying also improves the efficiency of product packaging, storage, and transportation (Sagar and Kumar, 2010; Olawuni *et al*., 2018). In this article, different drying methods applied in previous studies on banana flour are reviewed; the effects of each method on the chemical, physical, and nutritional properties of banana flour are also discussed such as the colour, bioactive compounds, and starch content.

2. Process of banana flour preparation

In general, cleaning, pre-treatment, drying, and size reduction are the main stages involved in banana flour preparation. Banana fruits are rinsed to remove dirt and soil by using tap water or sodium hypochlorite solution. This step is followed by skin peeling. Sodium hypochlorite is a well-known and widely used sanitizing agent for fruits and vegetables that could help control

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and reduce microbial growth (Sun *et al*., 2012; Rayo *et al*., 2015).

Pre-treatment is an important step that aims to prevent the enzymatic browning reaction by inactivating polyphenol oxidase (Razali *et al*., 2020). Two types of retreatments, namely, physical and chemical pre-treatment, have been proposed. Physical pre-treatment is commonly carried out prior to slicing, the banana is blanched or steamed at approximately 80°C (Olawuni *et al*., 2018). Chemical pre-treatment is carried out by soaking the banana in a chemical solution after slicing. Some pre-treatment solutions include potassium metabisulfite and citric acid (Ng *et al*., 2014; Rayo *et al*., 2015).

The banana is immediately subjected to drying after pre-treatment and then size-reduced, which involves grinding and sieving to produce the fine powder of banana flour. The development of a number of drying methods that could directly produce powder as the final product (Rahman, 2007; Domínguez, 2011, Guiné, 2018; Calín-Sánchez *et al.*, 2020) may avoid the need for grinding. Table 1 summarizes the operational parameters involved in the previous research on banana flour preparation.

3. Drying methods used in banana flour preparation

3.1 Natural drying methods

Natural drying refers to a drying process that uses natural resources (e.g., the sun) as a heat source (Maisnam *et al*., 2017). Natural drying is economical, but the uncontrollable process resulting from the inability to control temperature and drying duration due to weather uncertainties is often caused by inconsistent quality of the dried product (Altay *et al*., 2019). Therefore, the uncontrollable operating parameter of natural drying has led to the development of artificial methods to overcome its weaknesses.

3.1.1 Sun drying

Sun drying is a traditional dehydration technique that has been used since ancient times to dry various agricultural products (Fuller, 2000). In fact, this method is still used at present because it is fairly simple, inexpensive, and highly accessible. However, this method involves long drying durations that could last for 1–3 days depending on the weather conditions (Altay *et al*., 2019). In general, this method is carried out by placing the food material on trays and then laying the trays out under direct sunlight (Rahman, 2007). If drying requires more than 1 day, the sample is covered or kept indoors during nighttime (Ahmed *et al*., 2013).

The low performance of sun drying has been reported in many research studies and attributed to various uncontrollable operating parameters, such as temperature and humidity (Altay *et al*., 2019), which result in inconsistent product quality (Sagar and Kumar, 2010). Product safety may also be compromised by the risk of environmental contamination resulting from exposure to dirt, dust, and pests (Fuller, 2000; Rahman, 2007).

Youssef *et al*. (2018) revealed that banana flour prepared from sun drying has lower total phenolic, flavonoid, and tannin contents compared with oven-, vacuum-, and microwave-dried samples. Vu *et al*. (2017) demonstrated that sun drying results in the greatest loss of bioactive compounds. Meanwhile, Fadimu *et al*. (2018) reported that the lightness of banana flour prepared from sun drying is significantly lower than that of flour prepared from freeze-drying.

3.1.2 Solar drying

Solar drying is an improvised version of sun drying, which also utilizes the sun as a heat source (Guiné, 2018). This method is designed with equipment to exploit the heat energy from solar radiation and use it to dry samples (Akarslan, 2012). Thus, this method often employs higher temperatures and shorter durations than sun drying; ultimately, solar drying produces better final quality than sun drying (Ahmed *et al*., 2013). However, research by Fadimu *et al*. (2018) showed that solar-dried banana flour is darker in colour but has higher carbohydrate contents compared with sun-dried samples.

3.2 Artificial drying methods

Artificial drying methods employ an artificial heat source for heat and mass transfer during thermal drying. It is generally assisted by a set of electrical equipment that allows the control of the operating parameters during drying (Maisnam *et al*., 2017), which results in greater efficiency of moisture removal (Okoro and Madueme, 2004). The continuous advancement in drying technology has allowed the production of a dried product with desirable quality, stability and functionality (Mali and Butale, 2019).

3.2.1 Oven drying

Oven drying is a common and highly accessible drying method in which samples are placed in enclosed chambers and hot air is utilized as the drying medium (Rahman, 2007). This method generally involves heat, air circulation, and relative humidity (Ahmed *et al*., 2013). The circulation of hot air transfers heats energy to the food material, resulting in the evaporation of moisture from the surface of the material being dried

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Table 1. Summary of drying method in various research of banana flour

Drying Method	Raw Material	Pre-treatment	Thickness/ Temperature/ Duration	Reference
Sun drying	Ripe Cavendish variety (peel)	None	2 cm width / 34-45°C / 8 hrs	Vu *et al*. (2017)
	Green plantain, unknown variety (pulp)	Blanching, 1% KMS	N.A. / N.A. / 25.5 hrs	Fadimu *et al*. (2018)
	N.A. (peel)	Blanching	2 cm width / 30-38°C / 8 hrs	Youssef *et al*. (2018
	Green plantain, unknown variety (pulp)	Blanching, 1% KMS	N.A. / 50°C / 48 hrs	Fadimu *et al*. (2018)
Oven drying	Ripe Cavendish & Dream varieties (pulp)	0.5% SMS	2 mm / 60°C / 18 hrs	Abbas *et al*. (2009)
	Green *Klutuk* variety (pulp)	None	1 mm / 30, 40, 50°C / 15, 20, 24, 40 hrs	Setiafianti *et al*. (2017)
	Green plantain, unknown variety (pulp)	Blanching, 1% KMS	N.A. / 60°C / 24 h	Fadimu *et al*. (2018)
	Green Harton/ Horn variety (pulp)	None	N.A. / 70°C / 2 hrs	Pacheco-Delahaye *et al*. (2008)
	N.A. (peel)	Blanching	2 cm width / 70°C & 110°C / N.A.	Youssef *et al*. (2018)
Freeze Drying	Green Harton/ Horn variety (pulp)	1% Citric acid solution	1 cm / -18 °C 24 hrs (freeze), 5 hrs (lyophilized)	Pacheco-Delahaye *et al*. (2008)
	Green Mountain variety (pulp)	Blanching, 1% Citric acid solution	7 mm / -80 °C (freeze), -50°C 36 hrs (lyophilized)	Ahmed *et al*. (2020)
Vacuum Drying	Ripe Cavendish variety (peel)	None	2 cm width / 60, 80, 100°C / N.A.	Vu *et al*. (2017)
	N.A. (peel)	Blanching	2 cm width / 65°C & 100°C / N.A.	Youssef *et al*. (2018)
Microwave Drying	Ripe Cavendish variety (peel)	None	2 cm width / N.A. / N.A.	Vu *et al*. (2017)
	Green Harton/ Horn variety (pulp)	None	N.A. / 85°C / 4 min	Pacheco-Delahaye *et al*. (2008)
	N.A. (peel)	Blanching	2 cm width / N.A. / N.A.	Youssef *et al*. (2018)
Fluidized Bed Drying	Green Cavendish *Nanicão* variety (pulp)	0.1% Citric acid solution	4 mm / 55°C / N.A.	Rayo *et al*. (2015)
Spouted Bed Drying	Green Cavendish variety (pulp, pulp + peel)	0.5% Citric acid solution	N.A. / 80°C / N.A.	Bezerra *et al*. (2013)
Spray Drying	N.A. (biomass)			Oi *et al*. (2013)
	Green Cavendish *Nanica* variety (pulp)	1% Bisulphite solution	N.A. / 130°C / N.A.	Izidoro *et al*. (2011)
Drum Drying	Green Harton/ Horn variety(pulp)	None	N.A. / 152°C / N.A.	Pacheco-Delahaye *et al*. (2008)

N.A.: Unavailable information, KMS: Potassium Metabisulphate solution, SMS: Sodium Metabisulphate solution

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(Mazandarani *et al.,* 2014). According to John *et al.* (2014), oven drying is often used in small-scale product development and laboratory operations. However, while this method is relatively inexpensive to operate (Ahmed *et al*., 2020), the material to be dried requires prolonged exposure to high temperatures (Ebadi *et al*., 2011). Thus, the risk of deterioration in the colour, flavour, texture, and nutrient content of the final product is quite high (Kumar *et al*., 2019).

Fadimu *et al*. (2018) indicated that oven-dried banana flour is darker in colour and lower in protein content compared with other samples. Research by Vu *et al*. (2017) also demonstrated the dark brown colour of oven-dried banana flour. On the other hand, Ahmed *et al*. (2020) reported that oven-dried banana flour has significantly lower resistant starch contents compared with freeze-dried samples, as evidenced by the finding that the percentage of damaged starch in oven-dried samples is significantly higher than that in freeze-dried samples.

3.2.2 Vacuum oven drying

Vacuum oven drying is a dehydration method that takes place under vacuum conditions of reduced pressure and relatively low temperature (Rahman, 2007). This method is well-known for energy conservation because dehydration under a reduced-pressure environment does not require high heat energy (Parikh, 2015). The method is highly suitable for drying heat-sensitive food materials because it avoids exposure to high temperatures (Hubbard *et al*., 2021). Moreover, the absence of oxygen during the drying process prevents oxidative damage, resulting in better maintenance of colour, flavour, and texture compared with hot-air drying (Mohapatra *et al*., 2014).

Youssef *et al*. (2018) found that vacuum oven-dried banana flour demonstrates higher total phenolic, flavonoid, and tannin contents compared with oven- and sun-dried samples. Moreover, the total monomeric anthocyanin content of vacuum oven-dried samples is higher than that of freeze-dried samples. Vu *et al*. (2017) similarly observed higher levels of total phenolic contents in vacuum oven-dried banana peel flour compared with flour samples obtained through other methods. However, the flavonoid and proanthocyanidin contents of the former were lower than those of freeze-dried samples.

3.2.3 Freeze-drying

Freeze-drying, also known as lyophilization, is a dehydration process that involves three stages, namely, freezing, sublimation, and desorption (Antal *et al*., 2015). In this method, the food material is frozen, and the system pressure is reduced to sublimate the frozen water within the food material directly into the gas phase (Ahmed *et al*., 2013). According to Sagar and Kumar (2010), freeze-drying is one of the best dehydration approaches currently available because this method is highly capable of maintaining volatile compounds, minimizing the chemical and physical changes of the product (Calín-Sánchez *et al*., 2020), and avoiding the loss of flavour and aroma (Altay *et al*., 2019). In addition, the absence of liquid-phase water and utilization of low temperatures during operation leads to products with better quality by preventing food deterioration and microbial activity (Lin *et al*., 2007; Gaidhani *et al*., 2015).

Vu *et al*. (2017) demonstrated that freeze-dried banana peel flour maintains its bright yellow colour, whereas samples dried using other methods turn dark brown. In addition, the freeze-dried sample retained high levels of its bioactive compounds. Pacheco-Delahaye *et al.* (2008) showed that banana flour prepared by freeze-drying has a lighter colour than flour obtained by drum- and microwave-drying. Ahmed *et al.* (2020) showed that the browning index of freeze-dried banana flour is significantly lower than that of oven-dried samples.

Despite the superior performance of the freeze-drying method, however, this method involves a slow drying process of typically 20-30 hrs (Antal *et al.*, 2015; Calín-Sánchez *et al*., 2020). The long operating time involves high energy consumption, resulting in an expensive cost of operation (Domínguez, 2011; Altay *et al*., 2019). Hence, freeze-drying is not a common commercial method, instead, it is usually applied in the preparation of high-value products (e.g., astronaut food) (Rahman, 2006; Gaidhani *et al.*, 2015).

3.2.4 Microwave drying

The principle of microwave drying involves the conversion of electrical field energy into thermal energy, during which heat is transferred through molecular interactions (Parikh, 2015). During microwave drying, electromagnetic waves cause molecular oscillations within the food material, leading to heat generation and moisture removal (Calín-Sánchez *et al.*, 2020). According to Rahman (2007), microwave drying offers higher energy efficiency compared with hot-air drying. However, because of the absence of convection, this method is usually combined with other drying methods, such as microwave-vacuum drying (Mohapatra *et al.*, 2014) and microwave-osmotic dehydration (Sagar and Kumar, 2010), to increase the efficiency of drying.

Pacheco-Delahaye *et al.* (2008) showed that microwave-oven-dried banana flour has a darker colour

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compared with freeze- and drum-dried banana flour. Youssef *et al*. (2018) reported that microwave-oven-dried banana flour contains higher phenolic and flavonoid contents compared with vacuum-, oven-, and sun-dried samples. Vu *et al*. (2017) similarly indicated that microwave-dried banana peel flour has higher phenolic contents compared to freeze-, vacuum-, oven-, and sun-dried samples.

3.2.5 Spouted bed drying

Spouted bed drying is the improved version of fluidized bed drying, which is used to dry granular raw materials with coarse particle sizes that are too large for fluidization (Mujumdar, 2000). Spouted bed dryers allow better heat and mass transfer as a result of the agitation of the coarse particles of the raw material. Particle agitation results in the continuous renewal of the boundary layer on particle surfaces, which increases the contact area between the raw material and the heating medium during dehydration (Kahyaoglu *et al*., 2012). Figure 1 briefly illustrates the general mechanism of this drying method; here, the raw material is rapidly dispersed in the heated gas within the chamber (Rahman, 2007).

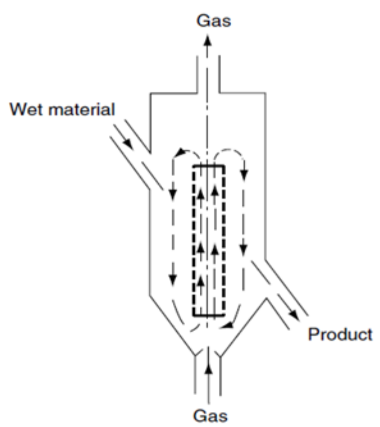

Figure 1. Schematic diagram of spouted bed dryer (Pallai *et al*., 2006)

Research conducted by Bezerra *et al*. (2013) found that spouted bed drying can retain the resistant starch content of banana flour, although drying was conducted at the temperature of starch gelatinization (80°C). The resistant starch content of raw bananas prior to drying was analyzed and compared with that of the flour obtained. Results showed no significant difference in the resistant starch contents of the samples.

3.2.6 Spray drying

Spray drying is an industrial-scale drying method that is widely used in the manufacture of dry powdered products originating from liquid raw materials (Guiné, 2018; Calín-Sánchez *et al.*, 2020). Spray drying involves the conversion of slurry raw materials into the powdered form of the end product and includes four stages, namely, atomization, contact between water droplets and hot air, water evaporation, and separation of the gas and powder (Rahman, 2007; Sagar and Kumar, 2010). The working mechanism of this method is briefly illustrated in Figure 2. Banana puree is used as a raw material instead of a typical sliced banana to produce banana flour by spray drying because this method requires a liquid feed (Maisnam *et al*., 2017).

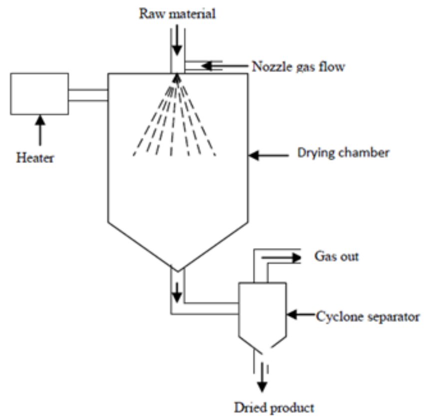

Figure 2. Schematic diagram of spray dryer (Maisnam *et al*., 2017)

Izidoro *et al*. (2011) investigated the properties of spray-dried banana starch and compared them with those of oven-dried samples. The authors' findings showed that spray-dried samples have insignificantly higher moisture and protein contents compared with oven-dried samples. By contrast, the fat and resistant starch contents of the spray-dried sample were insignificantly lower than those of the oven-dried sample. In terms of the physicochemical properties of banana starch, the solubility, swelling power, and water absorption capacity of the spray-dried sample were significantly higher than those of the oven-dried sample at 80°C. When drying was performed at 50, 60, and 70°C, these properties did not significantly differ between the spray-dried and oven-dried samples.

3.2.7 Drum drying

The drum drying method is commonly applied in the manufacture of dry powder originating from viscous fluid, slurry, or paste; here, the drying process takes place via the conductive heating of rotating drums (Rahman, 2007; Domínguez, 2011). As illustrated in Figure 3, the wet material is fed into continuously rotating drums to form thin layers adhered to the drum walls. The rotating drums are internally heated by condensing steam, which is responsible for the dehydration of the adhered layer of wet materials (Berk, 2009). Besides dehydration, the heat from the drum dryer also allows simultaneous cooking, which produces pre-gelatinized starch (Indiarto *et al*., 2021) as a result of irreversible thermochemical changes. Therefore, drum dryers are widely applied in the processing of starch powder used in the development of instant food products (Wan Daud, 2006).

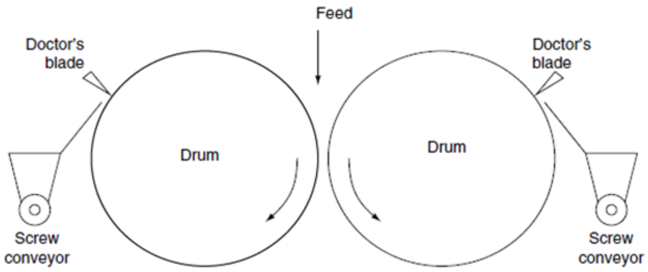

Figure 3. Schematic diagram of drum dryer (Wan Daud, 2006)

This method has been applied to prepare banana flour by Pacheco-Delahaye *et al*. (2018). The authors' findings showed that the moisture content of drum-dried samples is significantly higher than that of freeze-dried samples and not much lower than that of microwave-dried samples. In terms of starch content, the sample had significantly lower starch contents compared with the freeze-dried sample. However, the starch contents of the drum- and the microwave-dried sample did not differ significantly.

4. Conclusion

Previous research showed the effects of different drying methods on the quality of the resultant dried products. The final quality is often influenced by the operating parameters and the working mechanism of the method. The drawbacks observed in conventional methods have led to continuous innovations in drying technology and the development of complementary advanced methods. Banana flour should be prepared from a drying method that could preserve the starch content of green bananas while effectively producing flour of optimum quality. The selection of the appropriate processing method is critical in the food industry. Some factors that must be considered include the type of food material to be dried, the desired final quality to be achieved, and the operating cost and duration, among others. More importantly, the original properties of the product must be maintained.

Conflict of interest

The authors declare that no conflicts of interest.

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