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The effects of freeze, dry, and wet grinding processes on rice flour properties and their energy consumption

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ABSTRACT

This study attempted to replace the wet grinding process of rice with a freeze grinding process. The freeze grinding process involved soaking the rice samples in liquid nitrogen before grinding in a dry grinding machine. Three different types of grinders (hammer mill, roller mill, and pin mill) were used in both the freeze and the dry grinding processes. Wet grinding resulted in significantly ($P < 0.05$) smaller average particle size and a lower percentage of damaged starch than the alternative methods of grinding. Freeze grinding, especially using the hammer mill significantly reduced both the average particle size and the damaged starch content. Moreover, freeze grinding produced a higher yield after sieving in comparison with dry grinding using an identical grinder. In particular, freeze grinding with the hammer mill gave a significantly higher yield after sieving than dry grinding with the hammer mill. The wet grinding process had the significantly highest specific energy consumption (13,868 kJ/kg) due to the large consumption of electrical energy by the many machines in the process. The energy consumption of freeze grinding was similar to dry grinding. Consequently, the freeze grinding process was a viable alternative to the traditional wet grinding process.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. Broken rice, either from waxy rice or non waxy rice varieties, is used to produce rice flour by different size reduction processes. Rice flour is used to produce many kinds of food and desserts such as noodles, breakfast cereals, unleavened breads, snack food items, crackers, candies and baby foods (Bao and Bergman, 2004). Generally, there are three methods used to prepare rice flour: wet grinding, semidry grinding, and dry grinding (Chiang and Yeh, 2002). Wet grinding is a traditional method used to prepare rice flour and incorporates five distinctively consecutive processes: soaking, adding excess water during grinding, filtering, drying, and sieving; this process includes the use of many machines and much manpower. The costs associated with the flour loss, the high water consumption, the treatment of wastewater, and the high energy consumption call for an alternative method (Yeh, 2004). Dry grinding uses no water, does not generate waste water, and moreover, consumes less energy. Broken rice is ground with dry grinding machinery such as a hammer mill, pin mill, roller mill, or disc mill, etc. However, the level of quality of many food items (for instance noodles, made of dry ground flour) is not adequate for many consumers (Naivikul, 2004; Yeh, 2004). In the semidry grinding process, the properties of flour are intermediate to those of both dry and wet ground flour; in aspects of particle size, viscosity, damaged starch, etc. The semidry grinding process has three steps: soaking, drying to remove excess water (15–17% wet basis; %wb), and grinding with dry grinding machinery (Naivikul, 2004; Yeh, 2004). Nevertheless, such a method has some drawbacks such as the extended duration necessary to adjust the moisture content of the rice kernels, the excessive consumption of energy needed for the drying procedure, the undue consumption of water, and the generation of waste water. The type and method of grinding potentially has a profound impact on the physicochemical characteristics of the rice flours produced (Chen et al., 1999). Yeh (2004) stated that both the model and design of the grinder affect the performance, as well as the particle size of the flour. Generally, wet ground flour is better suited for the production of traditional rice based products than dry ground flour and semidry ground flour, regardless of whether the products are steamed or baked, as wet ground flour results in the lowest amount of damaged starch and the finest particle size (Chen et al., 1999).

When polished rice kernels are ground into rice flour, some starch granules are damaged due to the mechanical action during the grinding process (Nishita and Bean, 1982; Chen et al., 1999, 2003a; Solanki et al., 2005; Sharma et al., 2008). Chen et al. (2003a) indicated that the damaged starch and the particle size distribution were two key factors which affect the physicochemical properties and the application suitability of rice flour. Additionally,

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Nomenclature

W	wet grinding	*A*	electric current (ampere)
R	dry grinding with roller mill	*V*	voltage (volt)
H	dry grinding with hammer mill	*P.F.*	power factor
P	dry grinding with pin mill	*E*	electrical energy (kJ)
RF	freeze grinding with roller mill	*Es*	specific energy consumption (kJ/kg)
HF	freeze grinding with hammer mill	*P*	electrical power (kW)
PF	freeze grinding with pin mill	*t*	time (sec)

several components, with the exception of carbohydrate, affect the swelling of flour particles such as protein, ash, and lipids, etc., especially protein which is present in greater amount than the other components in the rice kernel and can block gel formation of the starch granule during heating (Naivikul, 2004). Damaged starch is a big concern in flour production, as it is separate from the intact granules impacting on both the solubility and the susceptibility to enzymatic digestion. Yeh (2004) stated that some grinding machinery causes higher temperatures than others and that is part of the reason why such machinery yields flour that has more damaged starch and does not function well. When the rice is ground, amylopectin molecules are broken down into low molecular weight fragments by the mechanical force applied. These amylopectin fragments block the formation of structures of leached amylose during heating which result in a less rigid structure (Han et al., 2002). Rice flour with a high damaged starch content is rapidly hydrated and hydrolyzed by α- and β-amylase (Megazyme, 2008). Flour with a fine particle size has more swelling power and is thus more prone to form rigid gel structures than course particle rice flour (Chen et al., 2003b).

Many parameters of the rice grinding process affect the characteristics of flour such as the grinding method, grinding machinery, the rice kernel hardness, the soaking process, rice cultivar (Chen et al., 2003a). The important characteristics of rice flour which affect the food quality, especially in rice noodles, are the particle size distribution, the amount of damaged starch, and the chemical composition (such as amylose, protein, and amylopectin etc.).

A new method was investigated that uses a freeze grinding process, which includes the freezing of rice with liquid nitrogen prior to dry grinding. At extremely low temperature, the samples are generally brittle and easily broken (Fan and Hsu, 1976; Gouveia et al., 2002; Devi et al., 2009). The objectives of the present study were to compare the performance of the freeze grinding, dry grinding, and wet grinding processes on yield, damaged starch content, average particle size, particle size distribution, microscopic structures, and energy consumption. Additionally, three types of grinders (hammer mill, roller mill, and pin mill) were used in both the freeze grinding and the dry grinding processes to compare the efficiency of the different machinery.

2. Materials and methods

2.1. Materials

Thai milled rice (Leuang 11 variety) was used in this experiment, with an amylose content of approximately 32–37% (dry basis) (Suksomboon and Naivikul, 2006). In each treatment in the grinding processes, 2 kg of rice was ground.

2.2. Grinding machines

For wet grinding, a super mass colloider (MKPB6–2, Masuko Sangyo, Japan) was used. For dry and freeze grinding, a hammer mill (AP-S, Hosokawa, Japan), a roller mill (Quadrumat Junior, C.W. Brabender, USA), and a pin mill (Ngow Huat Yoo Machinery, Bangkok, Thailand) were used.

2.3. Grinding techniques

2.3.1. Wet grinding

The broken rice kernels were steeped in water for 4 h to soften the rice kernels using ratio of water to rice of 2:1 (w/w). Then, the samples (rice and water) were ground using the super mass colloider. The flour slurry was poured into a thick cloth bag and centrifuged in a basket centrifuge for 10 min at 1492 rpm to remove the excess water. The wet ground flour was dried in a hot air oven at 40 °C for 12 h to obtain a moisture content of approximately 12%. The dried samples were ground by means of a hammer mill with a 0.5 mm sieve. Flour samples were passed through a 100 mesh sieve (Retsch, Germany) with 150 μm openings, packed in plastic bags and stored in a bucket at ambient temperature (about 25–28 °C).

2.3.2. Dry and freeze grinding

For dry grinding, the broken rice kernels were ground by the hammer mill with a 0.5 mm sieve, the roller mill, and the pin mill. Each sample was ground for two rounds to follow the manner of wet grinding (using the super mass colloider in the first round and the hammer mill in the second round).

For freeze grinding, the broken rice kernels were steeped in liquid nitrogen for approximately 1 min with a ratio of rice to liquid nitrogen of 2:5 w/v. The frozen samples were ground with the hammer mill, the roller mill and the pin mill. Subsequent to the first round of grinding, the flour sample was dipped into liquid nitrogen for 1 min prior to the second round of grinding.

Flour samples (dry and freeze ground) were passed through a 100 mesh sieve, packed in plastic bags and stored in a bucket at ambient temperature.

2.4. Performance assessment

2.4.1. Sample temperatures and grinding times

A thermocouple (Rixen, T-60) was used to measure the temperature of each rice or flour sample. In the first round, the temperature of the rice was measured before grinding and the temperature of the flour was remeasured after grinding. The temperature of the flour was measured again before grinding in the second round and remeasured after grinding in the second round. The temperature measurements were closely monitored, as fluctuations in temperatures were considered likely to affect the properties of flour. The grinding times were recorded with a digital stop watch. The grinding times were correlated with the temperature readings of samples.

2.4.2. Yield

The yield of rice flour was calculated using three formulas (Eqs. (1)–(3)):