Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 6(7): 188- 194
 (ISSN: 2141-7016)
jeteas.scholarlinkresearch.com

Mechanical Device for Starch Extraction during Rice Flour Fermentation: Cost Effective and Product Quality Consistent Approach

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Abstract

A fork-like paddle stirrer device designed and fabricated served dual functions in the batch rice fermentation; starch extraction and for aeration. The yield and characteristics of the device-associated fermentation was contrast with features from fermentation simulating indigenous practices using a wooden spoon stirrer. Contrasting features include continuous aeration with the device-associated system that ensured frequent microbe-substrate contact, higher percentage yield of starch and a short time to result (7 days versus 15 days with the wooden spoon stirrer). The wooden spoon stirrer system only permitted occasional agitation, yielded less starch but produced more quantity of protein-rich fermented rice granules. Lactic acid bacteria and yeasts were dominant fermentative flora and flourished at pH 3.5 to 4.5. The mechanical device consists of a long beam which furcated into five prongs. The prongs are made of two arms which bifurcate and a third arm that runs vertically from the base. The paddles are spade-like in shape with circular blunt ends. The paddles contain circular perforations with area of πr^2. This perforation serves as a sieve for extrusion of starch. The upper arm of the beam is attached to a thick rectangular beam at a fulcrum which allows it to rotate 360^o and two flexible spring cords that make the device to move both upward and downward. These mechanisms of operation ensure efficient agitation and facilitated the processes of extraction and aeration.

Keywords: rice starch, extraction device, fermentation, aeration, fermentative flora

INTRODUCTION

Fermentation technologies have remained the bedrock in the advancement of the food and pharmaceutical industries. The enhanced value which fermentation has added to agricultural produce especially starchy crops is unquantifiable. Fermentation benefits include enrichment of the human dietary through development of a wide diversity of flavors and textures in food, preservation of substantial amounts of food through alcoholic, acetic acid, lactic acid and alkaline fermentations, enrichment of food substrates biologically with protein, essential amino acids, essential fatty acids and vitamins, detoxification and removal of antinutrients (phytic acid, tanins and polyphenols) and decrease in cooking times (Blandino *et al*., 2003; Egounlety, 2002; Holzapfel, 2002; Ross *et al*., 2002; Steinkraus, 1994).

Traditional fermentations are likely to remain an important part of global food supply especially with the promotion of entrepreneur enterprise. This medieval process may receive significant enhancement with the use of starter cultures or genetic modification technology. Notwithstanding, the natives continue to evolve products and few examples from rice fermentation include Idli a fermented, thick suspension made of a blend of rice (*Oryza sativum*) and dehulled black gram (*Phaseolus mungo*) is used in several traditional foods in Southeast Asian countries. Idli is a low calorie, starchy and nutritious food, which is consumed as breakfast or snack (Nagaraju and Manohar, 2000). Steamed idli contains about 3.4% protein, 20.3% carbohydrate and 70% moisture. Philippine balao balao is a lactic acid fermented rice/shrimp mixture prepared by mixing boiled rice, whole raw shrimp and solar salt (about 3% w/w), packing in an anaerobic container and allowing the mixture to ferment over several days or weeks (Steinkraus, 1994). The chitinous shell becomes soft and when the fermented product is cooked, the whole shrimp can be eaten (Steinkraus, 1983). Boza is a highly viscous traditional fermented Turkish beverage made from cereals such as maize, rice and wheat flours. The preparation of boza is normally carried out by natural fermentation involving mixed cultures of lactic acid bacteria and yeasts (Zorba *et al*., 2003).

Starch is extracted at industrial scale mostly from maize, wheat, potatoes and cassava and to a lesser extent from rice, barley and sorghum because of the more complex technology required in cracking the small kernels of the latter group of starchy crops. Starchy crops provide approximately 75% of the nutritional energy and dietary fiber in human and animal diets (Charalampopoulos *et al*., 2002). The demand for starch is global from direct consumption as food to applications in chemicals and pharmaceuticals, textiles and the paper industry. The product that emerges from the extraction process known as native starch can be utilized in this form or as modified starch, or processed further into different kinds of sweeteners and for use in a wide range of fermentation processes. The production processes involved in starch extraction are basically the same for all crops and include milling and mechanical separation of the component parts. Cereals such as maize, wheat and rice are milled by grinding whereas tubers/roots such as potatoes and cassava are shredded using raspers. The subsequent separation of the component elements is carried out either on the basis of their different sizes using screens or filters, or different weights using gravitational forces in centrifugal separators (decanter centrifuges, nozzle centrifuges or hydrocyclones) (Alfa Laval, www.alfalaval.com).

Rice starch has been purified from endosperm using alkali, detergent, or by protease digestion (Juliano, 1980; Yamamoto *et al*., 1973). The only pitfall in the use of alkali and detergent as purifying agents is the alkaline or salty effluents produced and with protease the long digestion time of 24 h at near neutral pH and 38^{o} C which will result in high cost of production industrially. However the onus of this study is not to ride rice flour of its protein content but to reduce the calorific value by extracting crude (native) starch in whatever proportion before subjecting the rice particles to fermentation process to modify the final product which will serve for human food. The mechanical device introduced in this study is to aid in starch extraction and provide constant aeration in the batch fermentation vessel. The aim therefore of this study is to optimize the process of starch extraction and provide the environment and homogeneity required for microbial fermentative activity.

MATERIALS AND METHODS

Experimental Design:

The processes for the reduction of the calorific value of rice and microbial fermentation are outlined in Figure 1. The major steps are milling, starch extraction before and after fermentation and the use of fabricated mechanical device to aid starch extraction and provide continuous aeration within the fermentation vessel. In a parallel experiment, initial starch extraction was by mixing the slurry with a wooden spoon before screening. White rice (*Oryza sativum* L) was purchased from the local market and used in this study.

Batch fermentation was used to simulate conventional rural fermentation practices. Briefly, Rice grains were weighed out and milled into fine flour that can be retained on a sieve with pore size of 0.4mm but some can pass through a sieve of pore size 0.5mm. The flour was weighed and mixed with sterile water in a batch fermenting vessel in the ratio of 1:10 w/v. Within the fermenting vessel the slurry was stirred vigorously with the aid of the fork-like device fabricated and powered at a revolution of 1500rpm. The slurry was then poured and screened through a sieve with pore size of 0.3mm that will only allow the crude starch to pass through. The filtered starch was left to settle under gravity for 18-24 h, the supernatant decanted and the starch slurry spread over clean stainless pan and air-dried. The quantity of starch harvested per known weight of flour was recorded. The starch yield at each stage of extraction using wooden spoon or the mechanical device was determined.

The particles retained on the sieve were harvested and subjected to spontaneous fermentation under static conditions and continuous agitation at $20\pm2^{o}C$ as described below. In the static state the substrate in the fermentation vessel was stirred twice daily with a wooden stirrer; the lid of the fermenting vessel opened during each stirring operation and sample collection. In the second set-up, the fabricated device was fitted into the fermenting vessel and was powered electrically to rotate at a speed of 100rpm continuously; this occluded periodic opening of the vessel except during sampling. In a parallel experiment, initial starch extraction was by mixing the slurry with a wooden spoon before screening and followed by other processes as described above.

Mechanical Extraction and Agitation:

The step of agitation uses a paddle like mechanism which can be adapted for manual application or automated for industrial scale production. The mechanical device was designed and fabricated specifically for this study. The fork-like paddle stirrer (Figure 2) consists of a long beam (a) at the base (crab claw structure-b) which furcated into five prongs (c-g). The prongs are made of two arms which bifurcate (c, d and f, g), and the third arm (e) runs vertically from the base. The paddles are spade-like in shape. The ends are circular and blunt; this avoids abrasion of surfaces it comes in contact with during operation. The paddles contain circular perforations with area of πr^2. This perforation serves as a sieve and as particles pass through it starch is extruded. The upper arm of the beam is attached to a thick rectangular beam (z) at a fulcrum (y) which allows it to rotate 360^{o} and two flexible spring cords (x) that make the device to move both upward and downward. These mechanisms of operation ensured efficient agitation and facilitated the process of starch extraction from the flour and provided the convection current for substrate –microbe contact within the fermentation vessel.

Fermentation and Product Analysis

The rice granules after initial starch extraction were tested for starch content and thereafter subjected to natural fermentation either under static conditions or under aeration using the mechanical device. The ratio of starch flour and water in the fermentation vessel was maintained at 1:9 (10g to 90ml sterile water w/v). This step determines the duration of fermentation and the pattern of microbial succession. This stage is important in selecting potential starter culture organisms. Samples were collected from both set-ups on days 1, 3, 5, 7, 14, 15, 18 and 21 for both microbiological and physico-chemical analyses. Proximate analyses and nutritional content (protein, fats, carbohydrates and ash) tests were done for these products and the initial starch extract as described by Association of Official Analytical Chemists (AOAC, 2005) and Guzman and Jimenez (1992) with the total carbohydrate calculated by difference. The calorific values of the rice flour and fermented products were determined using Oxygen Bomb Calorimeter of model OSK 100A. The calorific value (Kcal/g) of the samples under test was calculated from the temperature rise in the calorimeter vessel and the mean effective heat capacity of the system (Sumner *et al*., 1983). Samples were cultured on MRS agar, Rose Bengal chloramphenicol agar, Malt extract agar, Yeast extract agar and CZAPEK DOX agar (all products of Biolab) for selective cultivation of yeast, molds and lactic acid bacteria. Incubation criteria were governed by the temperature and atmospheric requirements of the pre-determined organisms sought on each agar medium. Identification of isolates was done using a combination of microscopy, cultural features, and biochemical tests with the API bioMerieux kits.

Product Utility

The fermented rice granules were air or oven dried and toasted over dry heat to produce friable granular powder the fermented rice product. The yield from a pre-determined amount of rice flour was recorded. This product based on different treatment processes can be converted into puddings, flakes and fries or baked snacks. The fermented rice granular powder can also be soaked in water and taken direct as a meal. The native starch extract was air dried and served as binder, adjuvant and when fortified with minerals and vitamins can be consumed in gel form as custard meal

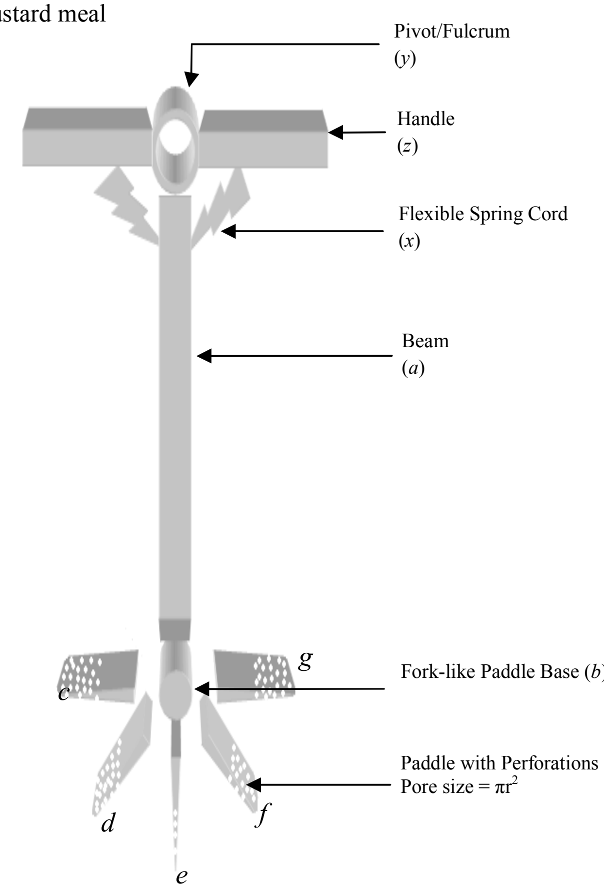

Figure 2: Mechanical device for agitation and dislodging of starch from grains

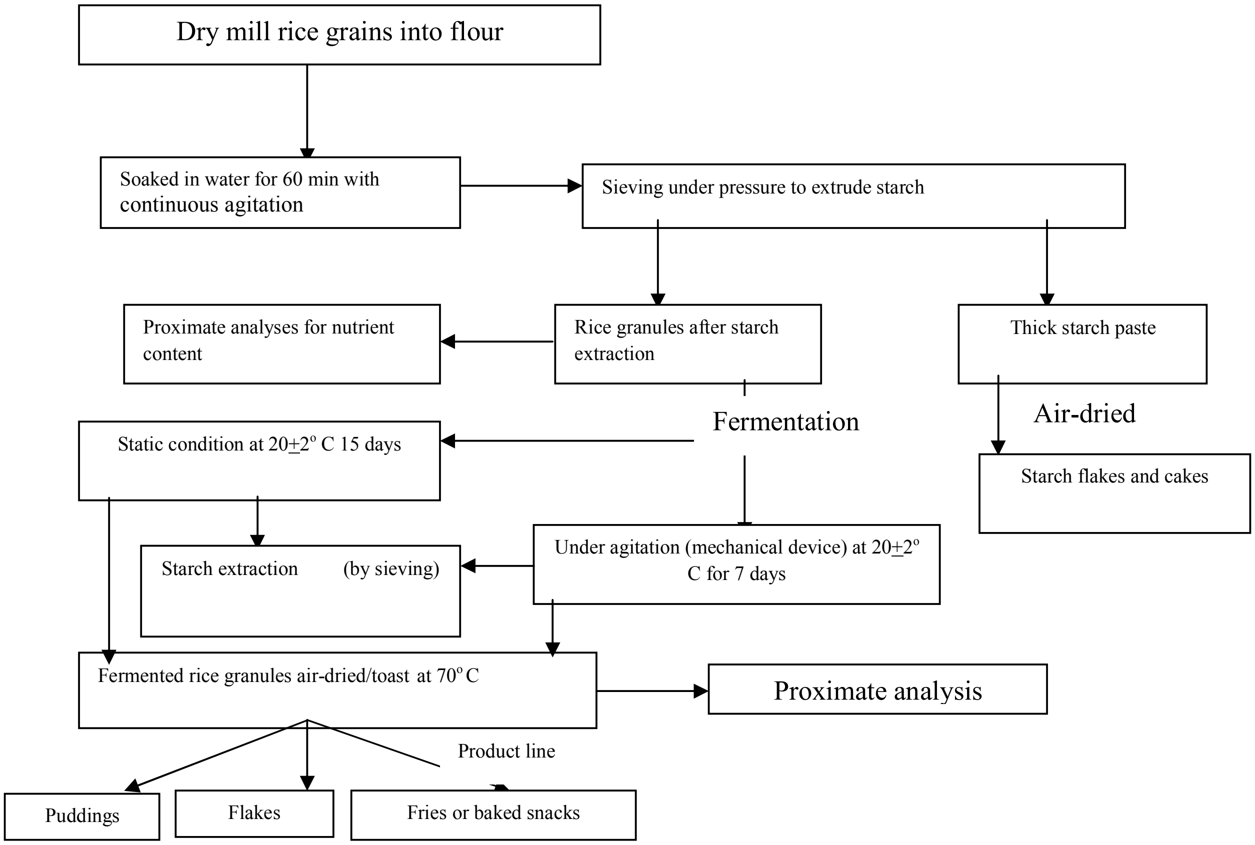

Figure 1: Flow chart for production of fermented rice meals

RESULTS

Comparing Tables 1 and 2 showed the reduction of starch content in the fermented product following initial starch extraction. From 80.5g in rice flour to 54g or 62g of fermented rice granules when extraction was done with the fork-like device or wooden spoon respectively. The calorific value of the product decreased from 357Kcal to 253Kcal and 264Kcal with the device-assisted and WS-assisted fermentation respectively. This gave an energy difference of between 104Kcal and 93Kcal. Other parameters such as protein, moisture and ash contents were relatively stable. With the device assisted fermentation it took 7 days for complete fermentation while with the WS-system complete fermentation was obtained on day 15. Total product yield was 80% with WS-system and 66% with device assisted system. Similarly the final protein content was higher in the WS-system. Acid pH was achieved rapidly in the device assisted culture and value as low as 3.5 was obtained. The lowest pH in the WS-batch culture was 4.5 and usually attained as from day 7. The microorganisms in both fermentations qualitatively were the same as shown in Table 3. However, the pH values showed that *Enterobacter*, *Bacillus*, *Enterococcus* and *Staphylococcus* are early colonizers. As the pH is lowered *Lactobacillus*, *Leuconostoc*, *Pediococcus* and yeasts become dominant fermenting flora. *Penicillium* and *Aspergillus* were isolated mostly in the WS-system and possibly represented contamination since these were not uniformly isolated from all fermenting vessels.

Table 1: Characteristics of rice flour

Properties	values
Carbohydrate (starch) (g)	80.5
Protein (g)	6.4
Ash (g)	0.2
Moisture (%)	11
Calorie (Kcal/g)	357
pH	6.8

Table 2: Method influenced properties

Properties	Device-assisted extraction	WS- assisted extraction
Starch yield‡ (%) BF	22	14
Starch yield (%) AF	12	6
TTR (days)	7	15
Product yield (%)	66	80
pH range (Mean)	3.5-5.5 (3.8)	4.0-6.5 (4.5)
Moisture (%)	11	11
Ash (g)	0.8	0.7
Protein (g)	3.8	4.6
Carbohydrate (g)	54	62g
Calorie (Kcal/g)	253	264

‡Percentage of weight of rice flour used
BF; before fermentation
AF; after fermentation
WS; wooden spoon
TTR; time to result (i.e., when final product was harvested)

Table 3: Predominant microflora and pH changes

Microflora	Under continuous aeration		Under static conditions#	
	pH range	Days predominant	pH range	Days predominant
Lactobacillus spp*	3.5-5.5	4-7	4.5-5.5	7-15
Leuconostoc mesenteroides	3.5-5.5	4-7	4.5-5.5	7-15
Pediococcus cerevisiae	4.0-5.5	3-7	4.5-5.5	7-15
Bacillus spp	4.5-6.5	2-7	4.5-6.5	7-15
Enterococcus faecalis	4.0-6.5	1-5	4.5-6.6	1-14
Staphylococcus spp	3.5-6.5	1-5	4.5-6.5	1-14
Enterobacter spp	5.0-6.5	1-3	5.0-6.5	1-7
Yeasts†	3.5-5.5	3-7	4.5-6.5	3-14
Aspergillus spp	3.5-5.5	5-7	4.5-6.5	7-15
Penicillium spp	3.5-5.5	5-7	4.5-6.5	7-15

#Represent batch wooden spoon was used as stirrer and stirring was twice daily.
**Lactobacillus delbrueckii, Lactobacillus fermenti and Lactobacillus lactis*
† *Geotrichum candidum, Torulopsis holmii, Torulopsis candida and Trichosporon pullulans*

DISCUSSION

The starch content of different variety of rice range from 45% to over 80% depending on the method of extraction (Ashogbon and Akintayo, 2012; Bhattacharyya *et al*., 2004) and to a great extent this amount of starch is consumed as whole meal (Marshall *et al*., 1990) and in many instances have been complemented with other starchy food especially maize, further increasing the carbohydrate burden of the meal. Thus for people with the propensity to be obese or diabetic, such high calorific intake may be of health risk. Furthermore rice starch for its flavor enhancing property and hypoallergenicity is used frequently in the processing of many value added products including gluten free bread, beverages, processed meat, low fat sauces, puddings and salad dressings (Deis, 1997). The array of uses to which rice, its flour and starch is put into requires that the calorific value of products intended for human consumption be low for health implication. That objective in part was achieved in this study by formulating a rice-based product low in calorie through two-steps starch extraction and fermentation. The end product the fermented rice granules can be served as a direct meal or used as raw materials for production of snacks and other rice based meals. The characteristics and uses of the starch extracted are the subject of another report.

It is instructive to note that the process applied in starch extraction differ from the conventional NaOH, detergent or protease digestion that produce higher yield of starch and at the same time free starch of its protein content (Baldwin, 2001; Singh *et al*., 2000; Morrison and Azudin, 1987). It was the purpose of this study to retain as much as possible the nutritional constituents of rice in the fermented product. The reduction in starch content with the paddle device was 34% as opposed to 20% with the wooden stirrer. This correlated well with the energy content of the final products from each method of starch extraction. The significant reduction in calorific value of the fermented rice granules by 104Kcal with the paddle device satisfied the objective of obtaining a low-calorie rice product for food. It is also worthy of note that the process did not ride the fermented rice totally of protein as with the device only about 40.6% protein was loss (from 6.4g in rice flour to 3.8g in fermented product). This product may fall into the same class as idli both in nutrient content and dynamics of microbial activity. The commercial advantage of introducing the paddle device include the reduction in time to result for product, product consistency as a result of uniformity of conditions throughout the fermentation vessel and reduction in rate of contamination of products. For the purpose of emphasis, this study did not consider the alkali, detergent or protease digestion methods of starch extraction because these methods leave little residues and the starch obtained is completely free of protein. This could have negated the object of this study of developing rice meal suitable for diabetics and those that desire low-starch/calorie meal.

Like many other cereal rice fermentation was characterized by succession of microorganisms and their occurrence in the fermentation vessel governed by the prevailing environment. Significant among which is the pH value. The present study showed *Enterobacter*, *Staphylococcus*, *Streptococcus* and *Bacillus* as early colonizers. A shift in flora to more predominant lactic acid bacteria and yeasts occurred as fermentation advanced and pH becomes more acidic. As stated earlier, Idli a low-calorie fermented rice is a product of natural fermentation involving a consortium of lactic acid bacteria and yeasts (Nagaraju and Manohar, 2000; Shortt, 1998; Purushothaman *et al*., 1993; Ramakrishnan, 1993; Chavan and Kadam, 1989). Lactic acid bacteria enhance flavor, nutritive value and available lysine content in food (Lee *et al*., 1999). Fermentation is such an important process which significantly lowers the content of antinutrients of cereal grains (Sindhu and Khetarpaul, 2001), provides optimum pH conditions for enzymatic degradation of phytate in cereals resulting in the release of polyvalent cations such as iron, zinc, calcium, magnesium into the medium (Blandino *et al*., 2003; Nout and Ngoddy, 1997). Fermentation processes have yielded major staples in Nigeria especially gari and fufu produce from cassava (Onyekwere *et al*., 1989; Adegoke and Babalola, 1988) and ogi a custard like meal from maize which is variously fortified either with soya or vitamins and is now a generally accepted meal for adults and for weaning (Teniola and Odunfa, 2001; Nwosu and Oyeka, 1998).

CONCLUSION

The aeration and starch extraction device is a simple and cost effective mechanism for accelerating starch extraction from any starchy food crop and creating sufficient aeration and mobility for organism-substrate contact for uniformity of products at each stage of fermentation. Further the device as used in this study facilitated the production of fermented rice with low calorific value and reduced duration of fermentation by 50% compared to fermentation under static conditions as practiced under unorthodox settings. The invention by this process achieves developing new food types from the microbial fermentation of rice. Industrially, this is of value as it creates many product lines and food meals from the staple which till now is consumed as a single diet of rice meal, though can be augmented severally as desired. The fabrication of a device assisted mechanism for small scale fermentation processes opens up business opportunities in the engineering and technical sector of the economy. In totality, the findings of this study have health related benefits in ameliorating obesity and diabetes, food and commerce as it has created new product lines from rice while at the same time has kept the industry within the reach of the peasants through the use of a low cost and efficient stirring device.

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