

ENHANCING THE PHYSICAL AND FUNCTIONAL PROPERTIES OF COWPEA  
PASTE USED IN AKARA PRODUCTION THROUGH MODIFICATION OF  
MILLING AND PASTE PREPARATION METHODS

by

AMANDIP SINGH

(Under the Direction of Yen-Con Hung)

ABSTRACT

The first objective was to determine if particle size distribution (PSD) of differently milled samples had an influence on hydration properties of the meals. The second objective was to select samples with particle size distribution most similar to the control and prepare *akara* from them. Functional properties of paste and *akara* quality were also determined. Sieve shaking and laser diffraction were used to determine PSD. Plate mill setting with the largest clearance yielded samples with 1558 microns mean diameter; this sample also produced *akara* that was most similar in proximate composition and textural quality to the control-WTM (wet milled). HM-2.54 (Hammer mill with 2.54 mm screen) was found to be the ideal sample as it had low amount of fat (~21%) and received high sensory ratings.

INDEX WORDS: Akara, cowpeas, milling, cowpea meal, hydration properties, particle size distribution, sensory evaluation

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## **DEDICATION**

To my parents, for all of their support and guidance throughout my life.

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## INTRODUCTION

Cowpea (*Vigna unguiculata*) is also known as black-eyed, crowder, and field pea in the United States. They were introduced into North and South America in the latter part of the seventeenth century, and the crop has been cultivated in the southern parts of the United States since the early eighteenth century. Today, cowpeas are mainly grown in the states of Georgia, California and Texas. These states account for 65% of the production in the United States.

Cowpea is a drought-resistant crop, a characteristic that makes it ideal for growth in East and West Africa. It is a high protein food and forms a major part of the African diet. Paste prepared from cowpea is usually consumed in the form of *akara* (fried cowpea paste), *moin-moin* (steamed cowpea paste), and *koki* (whipped and steamed paste with spices and palm oil). To make *akara*, whole cowpea seeds are soaked, decorticated by rubbing, and ground using a mortar and pestle (wet milling). Salt, onions, and, fresh peppers are added according to taste, and the paste is then whipped before frying. Whipping incorporates air into the paste thus giving the final product its much-desired spongy texture.

Traditionally, cowpea is processed by wet milling. This process takes a long time and is very tedious and laborious. An alternative processing technique is dry milling. The cowpea can be milled into flour and then hydrated to the desired consistency and used for *akara* production. This reduces soaking time and the process of preparing *akara* is shortened. Dry milling has its limitations, however, and research indicates that the dry

milled cowpea makes poor quality *akara*, which is dense and hard in texture. The poor quality of *akara* is attributed to the fine particle size of the flour. Fine milling breaks down the cell wall materials, thus destroying the fiber structure (Kethireddipalli et al., 2002a). This leads to poor water absorption by the flour, which subsequently affects the water holding (WHC) and swelling capacity (SWC) of the flour. Poor WHC and SWC lead to a product with tough texture and poor quality.

The method of dry milling used in processing cowpea also determines the paste properties and the end product quality. Dry milling can be done by using various mills, screen sizes, and clearances. This in turn leads to flours of varying particle size and hence, the end product made from these flours differs in quality too. The real challenge here is to produce flour that makes a similar or better product than the wet-milled one. This can be done by evaluating the effect of milling techniques on respective particle size distributions and then manipulate various factors to produce a particle size distribution similar to that of wet-milled paste. Section I involved studies of the effect of milling techniques, blending, and whipping on the particle size distribution and the changes thereof in it.

Our preliminary investigations showed that a large initial particle size plus a blending step during paste preparation considerably improves the functional characteristics of paste and quality of final product. In this study an attempt has been made to enhance and reproduce the quality of dry milled product by manipulating its particle size and blending times. Particle size distribution significantly influences paste functional properties and end quality of *akara*. After some preliminary studies we hypothesized that a dry milled product with a particle size distribution similar to that of

traditional wet-milled paste will translate into similar paste properties and end product.

In Section II of this study we have attempted to demonstrate this relationship. Overall this study examines the effect of milling and the resultant particle size on water holding capacity and swelling capacity of cowpea paste and texture, color, proximate composition and sensory characteristics of *akara*.

**SECTION I**  
**LITERATURE REVIEW**

### *Seed and content*

Cowpea (*Vigna unguiculata*), known as black-eyed, crowder, and field pea in the United States, is an important legume crop of East and West Africa (Prinyawiwatkul et al., 1996). It contributes a significant amount of protein and water-soluble vitamins to the African diet.

Cowpea seed is dicotyledonous, and the cotyledons form the major part of the seed. Each cotyledon contains parenchyma cells (60 to 100  $\mu\text{m}$ ) with reserve materials in the form of elliptical starch granules (11 to 20  $\mu\text{m}$ ). These are embedded in a proteinaceous matrix containing protein bodies (3 to 6  $\mu\text{m}$ ). The parenchymatous cells of the cowpea cotyledon are bound by a cell wall and middle lamella. Vascular bundles containing a large number of closely packed cells are scattered throughout the cotyledon (Sefa-Dedeh and Stanley, 1979a,b).

The outermost layer of the seed coat is the cuticle, and the palisade cells lie next to it. The palisade cells are responsible for hardness and permeability of the seed. Structure and thickness of the seed coat have significant effects on water absorption and dehulling characteristics. Varieties with thick seed coats were shown to have a slow initial rate of water absorption. The seed contains a micropyle and hilum, which play a major role in hydration properties of the seed by allowing moisture absorption (Sefa-Dedeh and Stanley, 1979a,b; Sefa-Dedeh et al., 1978; Enwere et al., 1991; El Faki et al., 1983).

Cowpea seed is composed of approximately 11% moisture, 23.4% protein, 56.8% carbohydrate, 3.9% fiber, 3.6% ash, 1.3% fat, and provides 343 calories/100g of seed (Deshpande and Damodaran, 1990). Cowpea also contains minerals such as potassium

(1024 mg/100g), phosphorous (426 mg/100g), magnesium (230 mg/100g), calcium (74 mg/100g), sodium (35 mg/100 g) and iron (5.8 mg/100g). The nutritive value of cowpea is also enhanced by the presence of vitamins such as niacin (2.2 mg/100g), thiamin (1.05 mg/100g), riboflavin (0.21 mg/100g) and  $\beta$ -carotene (18  $\mu$ g/100g) (Deshpande and Damodaran, 1990). Cowpea protein has a good quantity of the following essential amino acids: leucine (7.4 g/16gN), lysine (6.7 g/16gN), phenylalanine (5.7 g/16gN), valine (5.2 g/16gN), isoleucine (4.9 g/16gN), threonine (4.1 g/16gN), methionine (1.3 g/16gN), cysteine (1.1 g/16gN) and tryptophan (1.0 g/16gN) (Mosse and Pernollet, 1983). The low value of sulphur-containing amino acids is evident. Protein quality is synergistically improved in cereal-legume mixes. Cowpeas are rich in lysine and make good complementary food with cereals, which are rich in sulfur-containing amino acids such as methionine (Enwere and Ngoddy, 1986). As a recommendation for human diets, a weight ratio of 45 parts cereal grain to 15 parts cowpea could be used (Bressani, 1985). The cowpea carbohydrates (56.8% content) consist of 13% total sugars, 4% crude fiber, and 48% starch (Reddy et al., 1984; Longe, 1980). About half of the total starch is in the form of amylose (Bressani, 1985). The relatively high amylose content has been shown to cause slow digestibility *in vivo* (Rao, 1976). The amount of amylose in starch influences starch solubility, lipid binding, and other functional properties such as swelling, solubility, water absorption, gelatinization, and pasting, all of which affect cooking quality of cowpea and its acceptability. Amylopectin is responsible for solubility of starch granules (Bresanni, 1985; Reddy et al., 1984). A wide range of processing methods such as boiling, soaking, and germination have been used to increase the utilization of cowpea. Boiling, fermentation, and germination increased carbohydrate

digestibility of raw cowpea *in vitro* by 57.7%, 56.7%, and 51.7%, respectively, and may facilitate it *in vivo* to some extent. Roasting had a negative effect on carbohydrate digestibility (50.5%) *in vitro* (Rao, 1976; Reddy et al., 1984; Deshpande and Damodaran, 1990). Cowpea protein has a digestibility of 72%. Cooking improved protein digestibility of raw cowpeas, ranging from 87 to 92% (Khan et al., 1979). However, besides the nutritional components, cowpeas contain significant amounts of antinutritional factors that have to be eliminated to improve their nutritional quality and organoleptic acceptability. The major ones are trypsin inhibitors, tannins, and the oligosachharides, stachyose and raffinose (Wang et al., 1997).

#### *Cowpea cultivars*

Cowpeas are sold to the American consumer under a variety of names, e.g., field peas, southern field peas, acre peas, and crowder peas. Dry blackeye types are usually marketed as blackeye beans or blackeye peas. The term cowpea is rarely used in the American marketplace (Fery, 1985).

Most American cultivars are classified as blackeye, crowder, or cream types with the blackeye cultivar being the most popular among the three. Blackeye and its variant pinkeye are mainly used as dry seed. The name 'crowder' refers to the crowded appearance of peas in the pod. Crowder peas are the least liked of three types and are usually used for canning and freezing purposes (Hoover, 1966). The cream or white-eye types derive their name from the color of the hilum. The light-colored hilum contributes to an attractive appearance. The cream types are less starchy, succulent, and the most diverse group of cowpeas (Fery, 1985).

Sefa-Dedeh and Stanley (1979a) studied various cowpea cultivars to examine the relationship of microstructure to water uptake. They reported that different cultivars showed a similar cotyledon structure but had differences in seed coat structure and thickness, micropyle, and hilum size. This variation leads to differences in functional properties such as water holding capacity, swelling capacity, viscosity, and specific gravity. Sefa-Dedeh and Stanley (1979a) also noted that the structure and thickness of the seed coat has a significant effect on hydration properties. These observations hold even more significance in the case of wet-milled cowpea because the seed coat thickness would directly affect the moisture uptake and hence the end product quality. In the context of later research (Kethireddipalli et al., 2002ab), it can be seen that the seed coat and cell wall material contain fibrous material that significantly affects water uptake and end product quality.

#### *Factors limiting nutritional and functional quality*

Nutritional quality of food depends not only on nutrient content but also on nutrient bioavailability. In addition to its organoleptic quality, physicochemical characteristics of cowpea play a major role in its overall acceptance and consumption. Cowpea contains certain antinutritional substances such as lectins, trypsin inhibitors, condensed tannins (polyphenols), phytates, and flatulence factors that affect nutrient availability and reduce protein quality (Nnanna and Phillips, 1988; Deshpande and Damodaran, 1990; Sathe and Salunkhe, 1984). All varieties differ significantly in their antinutrient content (Preet and Punia, 2000).

Phosphates in plants are stored in seeds as phytates and are present in the outer aleurone layers of the cotyledons or the endosperm (Deshpande et al., 1982). Cowpea

has 0.44% phytic acid (Kumar et al., 1978). Phytates form a complex with dietary essential minerals and decrease their bioavailability to the body. Zinc binds to phytates more tightly than other minerals. Phytates also interact with proteins and reduce protein solubility and availability (Sathe and Salunkhe, 1984). This reduction in protein solubility adversely affects the paste's functional properties. Germination and fermentation decrease phytate levels, and soaking and cooking can also remove 50-80% of the endogenous phytate in bean seeds (Sathe and Salunkhe, 1984).

Polyphenols are located in the seed coats with negligible amounts in the cotyledons. Polyphenolic compounds adversely affect protein digestibility and may inhibit hydrolytic enzymes such as  $\alpha$ -amylase. Polyphenols also impart intense color and off flavors. Heat-stable tannins inhibit pectinases, cellulase, amylases,  $\beta$ -galactosidases, lipases and several proteolytic enzymes (Sathe and Salunkhe, 1984; Deshpande and Damodaran, 1990). Cowpeas have 0.03-0.59% tannins depending on the cultivar (Price et al., 1980). Tannin-protein complexes are responsible for growth depression, low protein digestibility, and increased fecal nitrogen. Germination helps lower tannin content in seeds (Deshpande and Damodaran, 1990).

The presence of protease inhibitors in cowpeas prevents complete utilization of proteins. These inhibitory activities are associated with trypsin (Prinyawiwatkul et al., 1996). Cowpeas (Variety IT84S-2246-4) have 13.02 mg/g trypsin inhibitors (Egounlety and Aworh, 2003). Each cultivar has a different amount of trypsin inhibitor activity. Trypsin inhibitors induce pancreatic enlargement in animals (Sathe and Salunkhe, 1984) but they are proteinaceous in nature and can be effectively controlled by cooking (Ogun et al., 1989; Egounlety and Aworh, 2003).

Lectins are proteins with an affinity for specific sugar molecules. Since most animal cell membranes have carbohydrate moieties, lectins may attach to these receptor sites under favorable conditions, resulting in the agglutination of cells (Sathe and Salunkhe, 1984; Deshpande and Singh, 1991; Osir et al., 1995). Lectins can be effectively reduced by cooking (Ayyagiri et al., 1989). Phytohemagglutinins (a specific kind of lectin) help the legume plant to protect itself against predation by vertebrates and invertebrates (Janzen et al., 1976).

Due to the absence of  $\alpha$ -galactosidase in humans, oligosachharides such as raffinose, stachyose, and verbascose are anaerobically fermented by the colon microflora to produce flatus-causing carbon dioxide, hydrogen, and methane (Plahar et al., 1997). Akinyele and Akinlosotu (1991) found that soaking and dehulling reduce the content of oligosachharides in cowpea. Even after removal of these oligosachharides, it was noted that flatulence production was not eliminated (Fleming, 1981). Fiber is one of the major indigestible components of the bean residue, which may be involved in fermentation and flatulence production (Kamat and Kulkarni, 1981). Hemicelluloses have been reported to increase hydrogen production in human subjects (Tadesse and Eastwood, 1978). Soaking beans in water and then discarding the soak water removes most of the oligosachharides from the beans. Depending on the cultivar, cowpea has 31.4 - 47.8 g/kg stachyose and 20.3 - 29.7 g/kg raffinose (Somari and Balogh, 1995). The same researchers reported a reduction in the amount of these sugars by application of *Aspergillus niger*  $\alpha$ -galactosidase. The addition of antibiotics and bacteriostats is another method that can be used for reduction of flatulence. These chemicals kill the colon microflora and hence prevent flatulence (Richards and Steggerda, 1966).

To improve the nutritional quality and effectively use the dry beans, removal of undesirable components is essential. Several approaches can be considered to accomplish this goal. Physical and chemical processing methods that can be used towards this objective are soaking, cooking, germination, fermentation, selective extraction, dehulling, membrane filtration, irradiation, and enzymatic treatments (Sathe and Salunkhe, 1984; Deshpande and Damodaran, 1990). In many cases a combination of two or more methods have to be used. Cell wall material has been reported to reduce bioavailability of legume proteins (Melito and Tovar, 1995). Dehulling is helpful in reducing tannins and phytates, which are mainly present in the seed coat (Ogun et al., 1989). Cooking generally destroys heat-sensitive antinutrients such as protease inhibitors, lectins, volatile compounds, and polyphenols (Wang et al., 1997; Ogun et al., 1989). Wang et al. (1997) reported that trypsin inhibitors and raffinose could be reduced by 80-90% after autoclaving the sample at 120 °C for 30 minutes. Germination is useful in removing certain unwanted and heat-stable components such as phytates, tannins, and the flatulence factors, whereas it has little effect on protease inhibitors and lectins (Deshpande and Damodaran, 1990; Sattar et al., 1989). Nnanna and Phillips (1988) reported a decrease in raffinose sugar levels as a result of controlled germination at 30 °C for 24 hrs. Fermentation inactivated trypsin inhibitors and lectins that are associated with the edible legumes (Prinyawiwatkul et al., 1996). Raffinose oligosachharides and phytates are also reduced during fermentation (Reddy and Salunkhe, 1980).

Resistance of cowpeas to cooking may be due to impermeability of seed coat or “hard to cook defect” (HTC), which is also common in other legumes. In HTC defect, the cotyledons do not soften during boiling even though the seeds absorb water

(Deshpande and Damodaran, 1990). Hence, the HTC defect causes increased fuel consumption and decreased nutrition for the human body. This defect mainly arises from inadequate climate control during storage. High temperature and humidity are the main causes (Liu et al., 1992a). However, these conditions (40 °C at 95% humidity) have been reported to have a beneficial affect by reducing the trypsin activity by 20 to 30% (Piergiovanni et al., 1993). Liu et al. (1992a) demonstrated that HTC defect in cowpeas progresses through an increase in cation uptake capacity followed by binding of cations to the pectin sites. This restricts starch gelatinization within the cell cytoplasm and lack of cell separation between cell walls. A related study (Liu et al., 1992b) reported that an increase in cation uptake capacity is not due to the action of pectinmethylesterase (PME) or demethylation of cell wall pectin. The role of cell wall pectin in legume hardening was also investigated in detail (Liu et al., 1993). They reported that lack of cell separation results from resistance of pectin to  $\beta$ -eliminative degradation and solubilization. Cell lignification via cross-linking of phenolics with cell wall proteins has been suggested as another possible cause of HTC (Hincks and Stanley, 1987). HTC seeds exhibit a reduction in water absorption and protein solubility (Hung et al., 1995). This affects the functionality of cowpea batter, because it is directly related to the proteins in paste, specifically, albumins (Phillips et al., 1988). Addition of calcium bicarbonate and a crude rock salt of carbonates (*kaun*) or sodium carbonate (*kawe*) are the traditional methods used in alleviating the problem of HTC in most Nigerian homes (Onigbinde and Ojeabulu, 1999; Ankrah and Dovlo, 1978). *Kawe* has been reported to lessen the cooking times for cowpeas (Ankrah and Dovlo, 1978). However, this

treatment also has a negative effect on *akara* because it promotes excessive browning. Citric acid has been suggested as a good alternative.

#### *Cowpea-based foods*

Cowpea pods are eaten as green vegetables or as dry mature seeds. These seeds can be cooked dehulled or undehulled, fried to make *akara*, steamed to make *moin-moin* and *koki*, fermented to make *tutu* in Brazil, *idli* and *dosa* in India, boiled, germinated, roasted, or made into soups and stews. Cowpea seeds can also be utilized by processing into flour or meal (Siegel and Fawcett, 1976).

Cowpea seeds are used as a staple food in many tropical and subtropical countries of the world. This is mainly because of their high protein content and hardy nature (Akpapunam and Markakis, 1981). Cowpea seed can be consumed as such by boiling, steaming, and roasting. Usually the seed is dehulled to rid it of the seed coat that contains anti-nutritional factors (Egounlety and Aworh, 2003). In the United States, cowpeas are usually prepared for consumption by boiling whole seeds (McWatters and Flora, 1980). Cowpea seed can also be dry milled into flour and used as an ingredient in other foodstuffs. Various studies have been done where cowpea flour partially replaced wheat flour to make bread, doughnuts and cookies (Mustafa et al., 1986; McWatters, 1982; McWatters, 1980; McWatters et al., 1995). Wheat flour replacement with up to 10% cowpea flour produced bread with improved protein quality and loaf volume (from 3.2 to 3.4 cc/g). At this low amount, the loaf volume was not affected significantly and the overall sensory ratings were acceptable also (Mustafa et al., 1986). The main problem with increased amount of cowpea flour was found to be the beany taste it imparted to the products (McWatters, 1980; Holt et al., 1992). Okaka and Potter (1979)

showed that acidified water (pH 4-6) soaking followed by blanching reduced the beany flavor of drum-dried cowpea powders in a porridge-like baby food formula.

Cowpea flour has also been used to produce baby-weaning foods. A composite of press-dried millet flour (70%) and cowpea flour (30%) had good nutritional quality and the ability to form smooth pastes upon hydration with tap water (Almeida-Dominguez et al., 1993). Cowpea flour has also been successfully used to produce chips by partially replacing cornstarch and wheat flour. This increased protein content and decreased fat and calories (Lu and Sanni-Osomo, 1988; Kerr et al., 2001). *Papad* (thin, wafer-like dried product made from pulse/cereal flour with spices in India) was made from cowpea flour by completely replacing the traditionally used blackgram flour. They were rated to be highly acceptable by both trained and untrained panelists (Bhagirathi et al., 1992). Wheat flour was successfully replaced with 24% cowpea and 46% defatted peanut flours to make qualitatively acceptable tortillas (Holt et al., 1992). Chinese-type noodles have been successfully prepared from wheat flour fortified with 7-21% defatted peanut and 4-12% cowpea flours. The protein content was appreciably improved but firmness and color were compromised (Chompreeda et al., 1988). Caygill et al. (1981) produced emulsion-stable imitation milk that was nutritionally comparable to cows' milk. Rao et al. (1988) prepared a yogurt-like product from dehulled cowpea seeds. The product was inferior to the control, but the attributes were in the acceptable range.

Fermentation and germination have also been widely used to increase the usage of cowpea-based products and reduce anti-nutritional factors (Obizoba, 1989; Giami, 1993; Zamora and Fields, 1979abc). Nutritively, fermentation led to an increase in limiting amino acids and riboflavin whereas niacin content decreased significantly

(Prinyawiwatkul et al., 1996). Fermentation was induced naturally at 25 °C for 4 days. Fermented cowpeas were used to prepare soups, which were not liked by consumers although they had an increased amount of limiting amino acids (Zamora and Fields, 1979abc; ). Nutritive value of many legumes has been reported to increase after germination (Vanderstoep, 1981; Uwaegbute et al., 2000). Hydrated seeds were germinated at 25 °C for 24 hrs. Germination has been shown to increase digestibility and protein quality (Nnanna and Phillips, 1989). Another major advantage of these two methods is that they require less energy and also they reduce the amount of energy required for further processing (Hesseltine, 1981). Cowpea meal has been successfully extruded into products when initial moisture content ranged from 20 to 40% and extruder barrel temperature ranged from 150 ° to 200 °C (Phillips et al., 1985; Kennedy et al., 1986).

Products made from cowpea paste are the most consumed in Africa. These products are *akara*, *koki* and *moin-moin* (Dovlo et al., 1976; Ngoddy et al., 1986; Mbofung et al., 1999b). *Akara* is considered to be the most popular cowpea dish in Africa (Reber et al., 1983). Traditionally, *akara* is made by soaking seeds, dehulling, and grinding. Cowpea seeds usually are soaked in cool water to loosen the seed coat and increase imbibition. The seed coats are removed manually by rubbing between the palms of hands or using a mortar and pestle. Cotyledons are then wet-milled by using traditional grinding stones or mortar and pestle. The paste is then whipped with a whisk made from wood or metal. Chopped onions, fresh peppers (hot or mild), and salt are added and mixed into the paste. This paste is then dropped into hot oil and deep-fried until the formation of a golden brownish crust (Dovlo et al., 1976; McWatters, 1983).

Dovlo et al. (1976) described the traditional method for preparation of *moin-moin*. Like many other cowpea dishes, this method requires high inputs of labor and time. The soaking period varies from 1-4 hrs followed by manual removal of seed coats. The cotyledons and other ingredients (onions, peppers, and salt) are then ground into a puree. Portions of puree are then wrapped in glossy non-absorbent plantain leaves and steamed for 1½ hr. These requirements and changing lifestyles have diminished the use of *moin-moin* in Africa (Adeniji and Potter, 1980).

*Koki* is a nutritious food usually processed by whipping cowpea paste containing spices and palm oil and then cooking by steaming. It is popular in Cameroon. Its preparation is almost the same as *moin-moin*. The only difference is that unlike *moin-moin*, *koki* has a spongy texture similar to that of a wheat flour baked cake. This is due to the prolonged whipping of paste just before the steam cooking (Mbofung et al., 1999ab).

### *Milling*

Milling generally involves the removal of bran, i.e., the pericarp, seed coat, nucellar epidermis, and the aleurone layer. Also the germ is removed because it is high in oil and can make the product rancid. So, milling increases the palatability and desirability of cereals and legumes. Dry milling is an attempt to separate the anatomical parts of the grain as cleanly as possible. Wet milling, in addition to clean separation of bran and germ from the endosperm, also separates the endosperm into its chemical components of starch, protein, oil, and fiber (Hoseney, 1986).

Milling usually involves constraints with regard to particle size. Particle size is controlled by using different screens and clearances. The type of mill used also has a

major impact on quality and yield of flour produced. Milling is divided into wet and dry milling.

Wet milling is used on grains to produce fiber, starch, and protein extracts (Hoseney, 1986; Hespell, 1998). Corn wet-milling produces starch, protein, and fiber (Perez et al., 2001). Wet milling involves soaking for a particular time at a particular temperature. Time and temperature of steeping is a major determinant for wet milling (Hoseney, 1986). Soaking parameters mainly depend on the hardness of seed.

Wheat stillage (by-product of fuel ethanol plants) is wet-milled to produce fiber-rich and protein-rich fractions (Abdel-Aal and Sosulski, 2001). Particle size and damaged starch are two key factors affecting the properties and application of flour from rice. Wet milling of rice is a very efficient way of producing flour that results in better products than those from dry milled flour (Chiang and Yeh, 2002). Buckwheat groats have been successfully wet-milled to produce starch, protein, and fiber (Zheng et al., 1998). Wet milling has been used in legumes to produce milk and other components. Soybeans are soaked, dehulled, and blended for production of soymilk (Kamaly, 1997).

Kethireddipalli et al. (2002a) reported that freshly wet-milled paste produced *akara* of superior quality. The texture profile analysis showed that the *akara* made from wet-milled paste was the least hard followed by blended meal *akara*. The blended and unblended *akara* did not show a significant difference in hardness values (22.8 N and 26.9 N, respectively). Overall, wet milling produced a superior paste and end product. Additional blending of paste made from dry milled cowpea meal made a significant improvement in the functional properties of paste and the end product quality (except hardness).

While milling and screening have been the main steps in obtaining high dietary fiber powders from cereals, wet milling and dry milling in conjunction are very important in producing fibers from fruits (Larrauri, 1999). Larrauri et al. (1996) reported that wet milling actually increased the production of dietary fiber from mango peels. This is probably because wet milling preserves the fiber structure better than dry milling. Hydratable flours are also produced by combined wet and dry milling operations (Phillips, 1982).

Dry milling is also used to extract and isolate fiber, protein, and other useful materials from plant sources (Hoseney, 1986). Commercially, dry milling is used to separate the anatomical parts of the grain as cleanly as possible. Different kinds of mills can be used for dry milling. Cereals are usually tempered to toughen the bran to make it resist being broken into small pieces during milling and to soften the endosperm and make it easy to grind (Hoseney, 1986). Removal of bran also helps in reducing the microbiological count of flour. Berghofer et al. (2002) observed that by separating wheat grain layers, the surface adherent contaminants are concentrated in bran and wheat germ. So the inner endosperm fractions have lower microbial counts and flour is the cleanest end product of the milling process.

McWatters et al. (1988) developed a dry milling method to produce cowpea flour that retains its functional and nutritional properties after milling. The seeds were decorticated by adjusting moisture to 25 % and held for 30 min. The seed dried at 50, 70 and 90 °C produced the ideal quality meal for *akara* production. Dry milling has some inherent advantages over wet milling (Phillips, 1982). Energy required for dry milling is

less as there is no drying step. Also, microbial contamination can be easily avoided and liquid waste streams are not generated.

Dry milling is carried out by using one or more types of mill. Commonly used milling techniques in cereal/legume milling are abrasive and impact milling. A hammer mill has rigid rotating blades called hammers that throw the material against the walls of the mill, thus resulting in breakage. Jindal and Austin (1976) reported that the rates of breakage of seed in hammer mill increased with a reduction in grain moisture content. The grain entering the mill, especially at a point on the periphery, experiences an impact force from the hammer and again when it hits the wall of the grinding chamber (Ajayi and Clarke, 1997). The Thomas-Wiley mill uses compression to fracture the grain. Its blades are fixed and have sharp edges and low clearance from the wall of the mill. There is a lot of wastage in a Wiley mill and the yield is low. A plate mill uses shear and compression as a means of milling grains. The abrasive action of the stationary and rotating plate performs the job.

Milling does not effect the overall composition of flour to a large extent but it does reduce the fiber content (Phillips, 1982). This is probably due to the abrasive action that leads to destruction of fiber structure and hence its quality and content.

Ward et al. (1995) reported that moisture, fat, protein, ash, and total carbohydrate composition of cowpea was not affected by milling and particle size. The amount of extracted starch showed an increase with smaller screen size. Kerr et al. (2000) observed that milling had a significant effect on the functional properties of cowpea flour, namely, water absorption, solids lost, and protein solubility. The finely milled flours had lower initial gelatinization temperatures as compared to coarser meals. Ngoddy et al. (1986)

successively milled cowpeas through a 1 mm screen and reported that *akara* or *moin-moin* prepared from the flour was dense, dry, and had a poor appearance. Most of the research on cowpea milling has dealt with the Morehouse mill, ultracentrifugal mill, hammer mill and Wiley mill with very small screen sizes such as 0.5, 1.0 and 2.0 mm (Kerr et al., 2000; Kerr et al., 2001; Kethireddipalli, 2002ab; Phillips, 1982; Ngoddy et al., 1986; Enwere et al., 1991; Enwere et al., 1998; McWatters et al., 2002; Enwere and Ngoddy, 1986; Chinnan et al., 1986; Henshaw and Lawal, 1993; McWatters, 1980; McWatters et al., 1988; Mbofung et al., 2002). No research reports which used larger clearance or screen milling were found in the literature.

Grain legumes used for further processing are traditionally consumed after the surface layers have been removed (Siegel and Fawcett, 1976). The traditional cowpea varieties have a black hilum, hence the name, black eye peas. The process of removing the outer seed coat or hull of the legume is commonly referred to as dehulling or decortication. Removal of the fibrous seed coat is said to improve the appearance, texture, culinary properties, and palatability of the legumes. It aids in digestion and effective utilization of nutrients in the body system. Melito and Tovar (1995) reported that the presence of cell wall limits *in vitro* protein digestibility in processed legume seeds. As described earlier, the seed coat contains significant amounts of trypsin inhibitors and tannin, which are known to bind soluble protein (Ogun et al., 1989). Traditionally, dehulling is carried out by rubbing the soaked seeds between hands to remove seed coat and hilum and make the seeds more palatable (Dovlo et al., 1976). The process of seed coat removal also leads to a reduction in fiber and protein content. Decortication can also be done by dry abrasive milling but the yield is low (Reichert et

al., 1979; Reichert et al., 1984). Reichert and Youngs (1976) compared abrasive and attrition mills for dehulling purposes and reported that the abrasive mill performed better for cereal legumes like millets. Cowpea cotyledons are much softer than cereal endosperm tissue, and this leads to high milling losses when abrasive dry milling is used (Phillips, 1982). Abrasive milling is recommended for hardy African varieties with tightly adhering seed coats. Some U.S. varieties (e.g. Mississippi Silver Hull and Crowder) have smooth, brittle, loosely adhering seed coats, which are easily removed by cracking and aspiration (Phillips, 1982).

#### *Cowpea meal*

An alternative to the tedious wet milling procedure is dry milled flour that can be hydrated to the desired moisture and flavored with salt, onions, and fresh peppers to make *akara* balls. However, the dry milled product was not qualitatively as good as the wet-milled *akara* (McWatters, 1983). This has been attributed to the grinding procedure that is used to make cowpea flour. Grinding of fiber not only causes particle size reduction but also alters its matrix structure. This lowers the water holding capacity and swelling capacity of dry hydrated meal (Cadden, 1987; Auffret et al., 1994). *Akara* made from a finely milled commercial flour exhibited poor water absorption, was very dense, and lacked crispness. The poor performance of the commercial Nigerian flour was attributed to the extremely small particle size of the flour (McWatters, 1983; Ngoddy et al., 1986). Structural and compositional components of cowpeas undergo considerable alteration during dehulling and milling (McWatters, 1983). Williams (1980) concluded that cowpea middlings (sized between flour and grits) were more suitable for *akara* preparation than flour.

This initial discouraging result prompted the researchers to look into the effect of dehulling, heat treatment, and various processing methods on functional properties of flour. Enwere and Ngoddy (1986) found that hydrothermal treatment (60 ° and 120 °C) applied to cowpea seeds prior to milling decreased essential functional properties such as nitrogen solubility, water absorption, and swelling and foaming capacities. The initial tempering for 16 hrs at 30 °C did not alter any selected functional properties of the flour. Henshaw and Lawal (1993) reported that processing methods, which involved wet dehulling, reduced functional properties, notably gelation and foaming capacity. This was attributed to loss of proteins in soak water. Mechanical dehulling eliminated the need to soak beans and did not affect the yield significantly. They also reported that excessive heat lowered nitrogen solubility and foaming capacity. Mechanical and manual dehulling showed better promise for *akara* production.

#### *Particle size distribution*

Particle size controls a number of properties important to ingredient functionality: viscosity, water-holding capacity, swelling capacity, flow properties, structure and properties of constituent fiber. Particle size distribution (PSD) has been widely used as a tool in the food industry for optimizing various food-processing operations. PSD is being used to optimize the flow properties of fuels, various powders, concrete, paints, ceramics etc. to aid in pumping, grinding, transportation, spraying, and other operations (Servais et al., 2002).

Food manufacturing operations also use PSD extensively to monitor production lines or for quality control in laboratories. PSD can be used in a food operation in two important ways. The more extensive use is similar to that of other industries, i.e.,

controlling viscosity and flow properties to aid in logistical operations (Servais et al., 2002). The other use of PSD is as a quality control measure and for product matching and development. PSD's usage for matching and development in the case of cereals, legumes, and other milled products has not been reported.

McWatters (1983) did a study on commercial Nigerian cowpea flour and made *akara* from it. The end product was dry, dense, and had a tough outer surface. This was attributed to the particle size distribution. The high percentage of small particles (48% in the 400-mesh range) in the commercial flour was the main reason for its poor performance. In comparison, the wet traditional paste had only 16% of its particles in the 400-mesh size. McWatters (1983) also reported that *akara* made from hydrated flour had a crusty surface. According to her, this led to a dry, tough texture and may have prevented sufficient amount of heat transfer to completely cook the interior. Ngoddy et al. (1986) observed that *akara* made from fine flour had decreased hydration and that reduced the amount of air incorporated. This in turn led to denser and less spongy texture. These researchers recommended that the flour be milled with 65-75% of the particles in the size range of 45-150  $\mu\text{m}$  and that seeds be dried at  $<60^\circ\text{C}$ . They also observed that with every pass of cowpea flour through the mill, the particle size distribution shifted towards the finer sieve sizes. Smaller particle size is associated with decreasing viscosity and hence the reduction in swelling capacity and water absorption capacity of cowpea flour.

There are various techniques that can be employed to measure particle size distribution of samples in wet and dry form. The important ones are: sieving, image analysis, laser diffraction, and the focus beam reflectance method (FBRM). Malvern

Instruments has published a paper on particle size measurement detailing various particle-sizing techniques (Rawle, 2002). Sieving is an extremely old technique. A set of sieves as specified in the American Society for Testing and Materials (ASTM) Standard E11 are used. Sieving is generally used for dry materials but cannot measure sprays and emulsions very effectively. It is also very time consuming and the operating methods have to be rigidly standardized (Rawle, 2002). Rawle (2001) reported some inaccuracies with the method. Too much powder may prolong the sieving process and effect the results due to small particles building up on the screening surface and reducing the aperture size (blinding). The passage of particles depends on the shape of particles and the shape of the sieve aperture. Spherical particles are mainly responsible for blinding whereas fibrous, narrow particles pass right through the sieves. Still, sieve analysis is an inexpensive method and produces relative data regarding changes in the size distribution. To produce accurate results, all parameters have to be standardized. Laser diffraction is also called low angle laser light scattering, but the generic term is “light scattering.” The applicable range according to ISO13320 is 0.1 to 3000  $\mu\text{m}$ . The method is based on the fact that diffraction angle is inversely proportional to particle size (Rawle, 2002). This method has the advantage of being fast, accurate, and gives repeatable results. It also works in a wide dynamic range (Crawley et al., 2002).

The functional characteristics of flours depend on the variety, storage conditions of seed, treatment prior to milling, type of milling, screen size or clearance used, and particle size distribution, among other factors. Iwuoha and Nwakanma (1998) reported a similar trend in flours from tubers. They also reported that finer flour particle size caused much higher viscosity and density than coarser ones at the same moisture content. The

larger surface area of the finer particles resulted in more rapid leaching of the soluble components, and this altered the properties of the continuous phase.

Kerr et al. (2000) studied the particle size distribution of cowpea flour, milled through 0.5, 1 and 2 mm screens, in suspension. They found that most samples produced a bimodal distribution of particle size. Only the collection pan (0 - 60  $\mu\text{m}$ ) fractions showed a monomodal distribution. They went on to record that the smaller-sized particles were suspended starch granules whereas the larger particles were partially or undissociated flour particles.

Kethireddipalli et al. (2002b) observed that blended cowpea meal paste did not perform as well as wet-milled paste because the meal had a small mean particle size distribution. It had been milled through a 1.6 mm hammer mill screen. An increase in screen size will certainly enhance the functional properties of blended meal paste. Decortication of seeds before milling removes the fibrous material and contributes to lower paste functionality.

Dziedzoave et al. (1999) correlated average particle size of cassava flour with human evaluation of smoothness and stated that particle size was an adequate measure of kinesthetic property. They also reported that average particle size was the most objective indicator for human evaluation of smoothness.

Kerr et al. (2000) observed that milling conditions and particle size influence water-binding properties of cowpea flour. Water binding capacity was lower in finely milled flour, while starch extraction was greater. These differences contribute to *akara* from finely milled flour being dense and unable to incorporate air to produce a spongy texture.

### *Hydration properties*

Water and fiber association is an important consideration when investigating the effects of fiber in the diet. Water influences the metabolic activity of fiber along the gut. Previous studies have shown that cereal fiber has a low water holding capacity (WHC) whereas that of vegetable fiber is high. This WHC can be influenced by the method used for fiber preparation and measurement of WHC (Robertson and Eastwood, 1981).

The WHC of fiber is a measure of the ability of a fiber source to immobilize water within its matrix. Altering the conditions of fiber preparation may result in a very different swelling capacity (SWC) and WHC for a fiber source (Robertson and Eastwood, 1981). Reichert (1981) isolated cell wall material (CWM) by a sieving procedure and observed that cell walls did not break down readily when soaked peas were macerated in a blender. Reichert (1981) also demonstrated photomicrographically that the size of CWM was many times larger than the size of other intracellular components. This intact structure of the cell wall preserves the ability of CWM to absorb moisture. They also observed that dry grinding of seeds before CWM isolation resulted in CWM of a very fine and unmanageable particle size. Many CWM particles were about the same size as the starch granules. In a soaked pea, CWM was very resilient and resistant to cutting action of the blades in the blender. It is apparent from these observations that increased hydration properties of a cereal legume are dependent on the CWM present and its structure.

Although water absorption and holding is mainly attributed to starch, pectic substances and other macromolecules, the chief water absorbing component of seeds is protein (Mayer and Poljakoff-Mayber, 1975). Reichert (1981) observed that protein

solubility in pea (*Pisum sativum*) flour was affected by milling intensity. Intense grinding led to reduction in the mean size of CWM and in protein solubility, thus negatively influencing hydration properties. Sefa-Dedeh and Stanley (1979a) discovered that intact seeds had a highly organized cellular structure and their anatomy and composition affected the water uptake capacity of the seed. The seed coat structure, its thickness, seed size, hilum size and protein content of the seed were the important factors.

The effect of particle size reduction on water-binding properties was also studied in detail by Cadden (1987). They observed that the change in physico-chemical properties (WHC and SWC) within the same product type is the result of changes in theoretical surface area. The type of milling used usually affects this surface area. They also recorded that alteration in physical structure of the fiber affected the water imbibing properties of fiber because the spaces available for free water in the fiber matrix were no longer present.

Kethireddipalli et al. (2002b) studied the role of cell wall material and soluble protein in paste functionality. The CWM from the wet-milled paste (control) had the highest SWC (41.06 mL/g) and WHC (22.12 g/g). Paste made from dry milled meal with additional blending was close behind. Fine flour paste performed the poorest. To demonstrate the effect of reduction of particle size on CWM by grinding, the CWM was ground using 0.08 and 0.50 mm screens. As expected, the WHC and SWC decreased with decreasing particle size of fibrous material. Additional blending was very significant in meal paste. Wet blending also significantly improved the WHC of meal paste from 2.34 g/g to 3.20 g/g, which was only 15% less than the control. Fine flour

paste was 62% less than the control. This clearly demonstrated that wet milling and additional blending had a positive affect on paste functional properties. The poor performance of flour was attributed to its smaller particle size. Wet blending built the turgor pressure in cells and made them rupture easily during blending. This led to better paste qualities after wet milling.

Auffret et al. (1994) reported that grinding decreased SWC and WHC of wheat bran, sugar beet, and citrus fiber probably by alteration and collapsing of the fiber matrix. Water binding and WHC of pea hulls were seen to increase after grinding, probably because of an increase in surface area and in the volume of pores (minute openings). Pea hulls, being rich in microcrystalline cellulose and therefore resistant to grinding, would increase the total volume of pore. These observations clearly underline the influence of the physical structure of fiber on hydration properties. Sangnark and Noomhorm (2003) observed that a decrease in dietary fiber particle size was associated with an increase in density and reduction in WHC of the fiber prepared from sugarcane bagasse.

McWatters and Chhinnan (1985) studied hydration time and level of hydration. It was recorded that the level of water used to hydrate cowpea meal had a greater effect on paste characteristics and *akara* quality than the length of time the meal was hydrated. A 60% moisture level and 60-minute hydration time was reported to be ideal for the meal. Kethireddipalli et al. (2002a) however reported that 15 minutes of hydration time was sufficient for making good quality *akara*. They also reported that flour paste had the least water holding capacity followed by meal paste and wet-milled paste.

### *Cowpea paste functionality*

Functionality has been described as any property, except nutritional ones, of a food or food ingredient that affects utilization (Pour-El, 1981). Kinsella (1976) defined protein functionality as those physical and chemical properties which affect the behavior of proteins in food systems during processing, storage, preparation, and consumption. Proteins are linked to functional properties such as solubility, water binding, gelation, foaming and color, whereas starch is associated with solubility, swelling, water absorption, viscosity, and gelatinization (Bressani, 1985). Particle size distribution in the solution also has an influence on paste functionality (Cadden, 1987). The final quality of all paste-based cowpea products depends on the functionality of the paste. Foaming capacity, hydration properties, and flow characteristics of the paste are the most important indicators of paste functionality in *akara* production (McWatters et al., 1988).

Foaming or whipping, i.e., the capacity to form stable foams with air is an important functional property of proteins. Foaming power (ability to form a foam) and foam stability (ability of foam to retain its original volume) are the two main factors that are determined by proteins (Kinsella, 1976). Food foams usually consist of gas (air) droplets dispersed in and enveloped by a liquid containing a soluble surfactant. The surfactant lowers the surface tension of the liquid, thereby facilitating deformation of the liquid and the marked expansion in its total surface area, against its own surface tension. The surfactant also lowers interfacial tension. The air droplets are surrounded by layers of cohesive protein, which have sufficient mechanical strength to prevent coalescence or rupture of droplets. Proteins that have the ability to cohere and the mechanical strength

to prevent coalescence form the best foams (Halling, 1981). Maximum incorporation of air reflects a real dynamic equilibrium between formation and destruction of air bubbles.

Cowpeas are expected to produce good foams because of their high protein content (~24%)(Bressani, 1985; Reddy et al., 1984). Various researchers (Aremu, 1990; Phillips and Baker, 1987; Chan and Phillips, 1994) have calculated the amino acid content of cowpeas and also grouped them in protein categories. The globulin fraction (salt soluble) was the major cowpea protein with 66% of the total followed by albumins (water soluble) with 24.9% (Chan and Phillips, 1994). Glutelins (alkali soluble) were a low 4.7% and prolamins (alcohol soluble) accounted for only 0.7%. Enwere et al. (1998) reported that loss of foam formation and stability resulted from the denaturation of mainly the albumin component of the cowpea seed during high temperature drying. They concluded that albumins contributed more than globulins to foaming capacity and stability during *akara* preparation. Any factor that affects the protein content or protein solubility will also have an affect on foaming ability of paste. Adverse storage conditions have been found to affect protein solubility and to harm foaming ability of pastes (Hung et al., 1995). High preheating temperatures before milling also had an adverse affect on protein solubility in solution (Ngoddy et al., 1986; Giami, 1993). Kerr et al. (2000) reported an increase in protein solubility with reduction in particle size of flour. This was attributed to the ability of water to penetrate the flour particles better and to carry away the soluble components. Giami (1993) reported that protein solubility was pH dependent in the case of heat-treated flour. They noted that heat treatment resulted in a 48.6% reduction in protein solubility of cowpea paste at pH 10, compared to raw flour.

Kethireddipalli et al. (2002a) studied the effect of wet and dry milling methods on the functional properties of cowpea paste and *akara* quality. They reported that blended meal paste had the closest specific gravity (0.778) to the wet-milled control (0.709). Meal paste without blending and flour paste had significantly higher specific gravity values. Flour paste had the highest protein solubility (57.85%) but the least viscosity and foaming ability. The wet-milled sample had protein solubility of 55.39% and showed a 29.9% reduction in specific gravity after whipping. Overall, wet-milled had the best functional properties followed by blended meal paste. They attributed the highly functional paste from wet milled paste to the large amount of soluble protein and fibrous CWM.

Hung and McWatters (1990) conducted a study on the effect of holding time on volume of whipped paste and *akara* quality. They recommended that paste be used immediately for best results. Holding up to 30 and 60 minutes provided good viscosity, dispensability, and ball shape. As holding time increased, the quality of *akara* deteriorated because of foam destruction. Mbofung et al. (2002) reported that increasing the whipping speed increased the swelling, which is a desirable trait. Optimum swelling was reported at the end of three minutes of whipping at high speed. Whipping time has to be worked out because prolonged whipping can cause formation of smaller, unstable bubbles.

Germination was found to increase foaming ability of cowpea flour but, like fermentation and heat treatment, decreases the foam stability compared to raw sample (Giami, 1993). Foaming properties of proteins are influenced by the protein source,

method of preparation, composition, solubility, concentration, pH, temperature, presence of salt, lipids, sugars, and duration of heating (Kinsella, 1976).

Hydration and flow characteristics of the flour and paste are other important indicators of paste functionality. Good hydration capacity of flour determines the batter consistency, which in turn leads to good end product quality. Viscosity is used as an indicator to determine good batter consistency. It mainly depends on the particle size distribution of flour and the amount of moisture added to it. The amount of cell wall material present to absorb this moisture also has a major role (Kethireddipalli et al., 2002b). Rehydratable flours with small mean particle size have been found to make pastes with low viscosity and poor dispensing properties (McWatters, 1983). Moisture content in the paste has to be optimized for better comparison between different samples. McWatters et al. (2001) reported that cowpeas with different genetic background varied in paste characteristics and *akara* quality. Adjusting the paste moisture content to levels above or below the 65% normally used for preparing *akara* from the blackeye variety improved paste performance for pinkeye, white-eye, and white acre varieties but not for the crowder variety. These researchers also reported that the white-eye paste had the lowest specific gravity and highest viscosity as compared to other major cowpea varieties (McWatters et al., 1999). Further, they showed that viscosity after whipping was a good indicator of end product quality.

### *Dietary fiber*

The term “dietary fiber” was first used in 1953, in place of “crude fiber,” to refer to the non-digestible residue in foods (Potty, 1996). Dietary fiber was later defined as the portion of foodstuffs, derived from plant cells and resistant to hydrolytic digestion by the

alimentary enzyme system in human beings, which consists of hemicelluloses, celluloses, lignins, oligosaccharides, pectins, gums and waxes (Trowell, 1974). Cummings and Englyst (1991) suggest that for analytical purposes, dietary fiber should be defined as the non-starch polysaccharides (NSP) in plant foods, since the best index of plant cell wall material in food is its NSP content, which can be accurately determined. Cowpea has 0.43 g/100g soluble and 4.11 g/100g insoluble fiber (Li et al., 2002). The soluble fiber represents the nutritionally important fiber. This is lower than other legumes such as bean, chickpea, faba bean, lentil, and pea (Carnovale et al., 1990). The major portion of the dietary fiber is present in the cell wall material for the seed.

Dietary fiber can be divided into soluble and insoluble fractions. The viscosity of soluble dietary fiber is responsible for slower digestion and absorption of nutrients, and lower levels of blood cholesterol and glucose. Insoluble dietary fiber aids in increasing fecal bulk and decreasing intestinal transition time (Potty, 1996). These physiological effects of dietary fiber can be correlated with their particular physico-chemical properties.

Various researchers have used fiber as an ingredient to improve the texture of food products. Ang and Miller (1991) used powdered cellulose to improve cake volume and texture; 110- micron cellulose helped in stabilizing the foams by increasing the viscosity of batters. It also decreased the specific gravity of batters up to 4% of cellulose content. They also successfully used cellulose to reduce fat content in various foods. The batters were composed of 1% cellulose by weight. Fernandez-Garcia et al. (1998) studied the effect of fiber fortification on yogurt and reported that 1.43% insoluble oat fiber improved body and texture of yogurt sweetened with sucrose. Peach dietary fiber was used as an ingredient to produce reduced-fat muffins (Grigelmo-Miguel et al., 2001).

They observed that with increasing concentration of fiber, the muffins became redder and yellower. Addition of 5% fiber decreased the fat content by 30% and increased moisture content by 100%.

#### *Consumer acceptability and marketing*

Acceptability of a product is very important for it to be produced economically and be useful. Various researchers have evaluated *akara* acceptability and its sensory characteristics. McWatters et al. (1983) studied sensory characteristics of *akara* and observed that appearance and color ratings were significantly higher for decorticated than for whole seed products. They reported no difference in flavor, mouthfeel, or overall liking due to the process treatment. There were significant differences in texture profile analysis, but the panelists did not discern these differences in terms of mouthfeel. McWatters et al. (1997) also reported that decorticated product was more acceptable than the nondecorticated product.

*Akara* can be marketed best in the pre-cooked, frozen state, so that it can be reheated shortly before consumption by the consumer (McWatters et al., 1992). The major constraint to marketing *akara* as a frozen supermarket item is that its quality is not comparable to that of fresh-made product. Tan et al. (1995) studied reheating conditions for *akara* and developed a protocol. They recommended using frying for reheating and to keep the initial cooking time 50-100 sec. With 75 sec initial cooking, reheating oil temperature could range from 152 °C to 180 °C. They also reported sensory and physical characteristics of *akara* that were close to freshly prepared product. Microwave and conventional reheating were not recommended because they led to a less spongy and drier product, respectively. Patterson (2002) developed a protocol for reheating *akara*

from the frozen and refrigerated states. Samples were reheated from the refrigerated state in a conventional oven for 6 min at 204 °C. In the case of frozen sample, the reheating time was increased to 12 minutes at 204 °C.

Misra et al. (1996) studied acceptability of *akara* by teenaged American consumers as a fast food alternative. They discovered that *akara* could be targeted toward young consumers of non-white ethnic background and customers who ate at fast food establishments more often. They also suggested that *akara* should be promoted as a nutritious fried food.

Patterson et al. (2002) used an untrained consumer panel for a study of *akara* made from California Cream, Blackeye, and a mixture of California Cream and Kunde Giraffe (2:1) varieties. There were no significant differences in sensory ratings of *akara* made from these cultivars, and all samples received acceptable ratings for all attributes. *Akara* from the California Cream variety received slightly higher ratings for all sensory attributes and overall acceptability than *akara* from the other cultivars.

Some researchers have used germinated cowpeas to make *akara*. Germination was reported to decrease anti-nutritional factor content, but it reduces the acceptability and flavor quality of *akara*. This was attributed to fermentation which led to deterioration of product quality. Germination led to an increase in protein content and sugars. This in turn gave intense Maillard reaction, which adversely affected the color (Uwaegbute et al., 2000).

#### *Modified wet milling*

The traditional methods used for *akara*, *moin-moin*, and *koki* production were modified for ease of operation and laboratory conditions. These modifications also

decreased the preparation time for these products and made the process less labor intensive. The seed is soaked for 3 hours in cool tap water. The excess moisture is drained and the seeds are coarsely chopped in a food chopper. The chopped peas are then blended for 5 minutes with additional water to obtain a smooth paste of appropriate consistency. This smooth, diluted paste is then whipped for 1.5 minutes. The ingredients (onions, fresh peppers, salt) are stirred in and the paste is dropped by spoonful portions into hot oil (193 °C) and fried for 2 minutes for making *akara* (Patterson et al., 2002). Blending and whipping are important steps in processing of cowpea into *akara*. Blending clearly aids in reducing the particle size of paste to a more acceptable level and thus aiding in better distribution of moisture. Whipping incorporates air into paste thus making it foam and giving it good dispensing properties and frying qualities (Mbofung et al., 2002). Cowpeas can be decorticated or used whole. McWatters et al. (1993) reported that paste prepared from whole seeds (California Blackeye 5) was more viscous and dense than the decorticated paste yet produced *akara* that received similar ratings for flavor, mouthfeel, and overall liking to those of *akara* made from decorticated seeds. Also, *akara* from whole seeds took up less fat (23.9%) as compared to that from decorticated seeds (31.8%).

The procedure for making *koki* has also been modified. Cowpeas are soaked in water at 37 °C for 2 hours and then ground into a paste with a hand mill. After this, a measured amount of lukewarm distilled water, salt, and palm oil are added. The paste is then whipped to a uniform color. The whipped paste is placed in greased aluminum cups and steamed in a steam cooker for 90 minutes (Mbofung, 1999b). *Moin-moin* is prepared

by the same modified method with the only differences being that the water added to wet-milled paste is at 70 °C and no palm oil is added (Ngoddy et al., 1986).

Various researchers have tried to make *akara* from HTC seeds and meal. Hung et al. (1995) reported that *akara* made from HTC seeds was dense and compact. The batters prepared from HTC meal could not be formed/dispensed mechanically. The balls sank to the bottom of the pan when dropped into hot oil. The poor functional properties of the batter were also apparent in the color and textural properties. McWatters et al. (2002) reported that storage of cowpea meal for up to 24 months at -18 and 21 °C retained foam and flow properties essential for production of good quality *akara*. The functional and nutritional properties of cowpea meal were adversely affected by storage at 37 °C. Mbofung et al. (1999a) suggested the approach of blending HTC seeds with normal cowpea for *akara* production. They reported that the *akara* made from composite paste had a relatively improved amino acid profile and that the bulk density of *akara* increased with increasing level of HTC beans. No overall differences were observed in *akara* made from cowpea substituted with up to 50% HTC beans. Mbofung et al. (1999b) found that *koki* produced from cowpea paste replaced with 40-50% HTC beans (*Phaseolus vulgaris*) was highly accepted by the consumers.

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**SECTION II**

**EFFECT OF MILLING METHOD ON SELECTED PHYSICAL AND  
FUNCTIONAL PROPERTIES OF COWPEA (*Vigna unguiculata*) PASTE**

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### Abstract

Particle size distribution (PSD) of cowpea meal is an important determinant of paste functionality and end product quality. Samples from various mills and screen sizes were used to determine PSD, water holding capacity (WHC) and swelling capacity (SWC). Hammer mill (1.73 mm screen) meal had a  $d_{gw}$  of 221 microns, whereas PM-360 (Plate mill with one complete turn ( $360^\circ$ ) of clearance) meal had a  $d_{gw}$  of 1559 microns. All other milling processes resulted in meal with an intermediate size. To reduce the particle size of cowpea pastes, cowpea meals were blended in a blender before whipping. Blending increased the WHC within a range of 44.4% for the wet-milled paste (WTM) to 315.5% (PM-360) and increased the SWC from 74.3% (WTM) to 214.1% (PM-180, plate mill with clearance of one-half turn ( $180^\circ$ )). In general, larger initial  $d_{gw}$  of the paste led to greater improvement in hydration properties after blending.

Keywords: Cowpeas, particle size distribution, hydration properties, milling, cowpea meal

## Introduction

Legumes are a major source of protein and calories in the developing countries, especially in Africa (Henshaw and Lawal, 1993). Grain legumes like cowpea are ideally suited for the African climate because of their hardy and drought-resistant nature (Cruz de Carvalho et al., 1998). In Africa, cowpea is consumed in the form of *akara* (seasoned and fried cowpea paste), *moin-moin* (steamed cowpea paste) and *koki* (whipped and steamed paste with spices and palm oil), as well as many soups and stews featuring cooked, whole seeds.

*Akara* is one of the main forms of cowpea consumption in West African nations (Reber et al., 1983). Cowpea seeds are soaked and decorticated before grinding and whipping. Blending and whipping are important steps in processing of cowpea into *akara*. Blending clearly aids in reducing the particle size of paste to a more acceptable level, thus aiding in better distribution of moisture. Whipping incorporates air into paste thus making it foam and giving it good dispensing properties and frying qualities (Mbofung et al., 2002). Spices and peppers are added according to taste and the paste is fried in hot oil (Dovlo et al., 1976). This preparation method is known as wet milling. Normally it takes about 8-12 hours to soak the seeds and prepare *akara* by this tedious and time-consuming method. The method has been modified and fine-tuned for laboratory conditions and reduced the preparation time to 3-4 hrs.

An alternative to wet milling is dry milling and the meal is rehydrated for *akara* production. This involves milling of seed in a suitable mill followed by adding an appropriate amount of water to meal before whipping. The dry milled paste then follows the same preparation steps as for the wet-milled product. This technique reduces the

preparation time to 15-20 minutes. Different milling technologies can be used for this purpose. By using various screen sizes and adjusting the clearance, we can obtain cowpea meal with different particle size distributions. It has been proposed in various studies that particle size distribution is a major factor that determines the end product quality (McWatters, 1983; Ngoddy et al., 1986; Phillips et al., 1988; McWatters, 1988; Kerr et al., 2000; Kerr et al., 2001; Kethireddipalli et al., 2002a,b). The effect of milling on functional properties of cowpea flour has been duly noted (Kerr et al., 2000). These researchers also reported that milling affected thermal properties of cowpea flour by lowering gelatinization temperatures for finely milled flours. Horvath et al. (1989) observed that protein content in pea flours depended on particle size distributions of samples.

Previous studies on production of *akara* from ready-to-use fine cowpea flour have shown that the end product is dry, tough, and has a hard crust (McWatters, 1983; Ngoddy et al., 1986). This was not acceptable to consumers. The poor performance of the flour has been attributed to the fine milling of cowpea seed. A commercial Nigerian flour (McWatters, 1983) with more than 81% fine particles (as collected on the fine sieves of 100, 200 and 400-mesh) performed poorly for *akara* making.

Dry milling also greatly reduces the fiber particle size. This reduction in fiber size adversely affects both its hydration and thickening properties (Kethireddipalli et al., 2002b). If the fiber structure is modified, the ability of fiber to entrap water within its fiber matrix is also affected (Cadden, 1987). In the case of cowpea paste, the effect is adverse. Some researchers (McWatters et al., 1988; Kethireddipalli et al., 2002a,b) have reported significant improvement in paste functionality and *akara* quality by additional

blending of paste when using cowpea meal with an intermediate particle size, between flour and grits.

In preliminary studies, it was noted that paste prepared from finer flours held less water, showed a lesser reduction in specific gravity after whipping (i.e. poorer foaming), and was more difficult to dispense than pastes made from coarser meals. The affect of milling technique on particle size can be quantified by calculating the corresponding hydration properties of water holding capacity (WHC) and swelling capacity (SWC) of samples.

In this investigation, the effect of milling method, blending, and whipping on particle size distributions of various samples in the dry and wet state was evaluated. The resultant changes and differences in hydration properties (WHC and SWC) were also measured.

## **Materials and Methods**

### *Preparation of cowpea meal*

Cowpea seeds were obtained from Inland Empire Foods, Riverside, California, U.S.A. All the seed used in this study was of the variety “California Cream” that was undecorticated. The “California Cream” seeds lack seed pigments and the undecorticated seeds have been reported to perform equally well as decorticated “Blackeye” seeds (McWatters et al., 1993). A small amount of seed (2g) was ground and its moisture content determined using a vacuum oven (18 h, 70 °C and 25 mm Hg). The moisture content was found to be 10.12%. The seed was milled using three different mills, namely, plate mill (PM), hammer mill (HM) and Wiley mill (WM). Wet milling was used as the control and will be described later. Screen sizes of 1.73 mm (HM-1.73) and

2.54 mm (HM-2.54) were used with the hammer mill (Champion, Model no. 6X14, Champion Products Inc., Eden Prairie, Minn., U.S.A.). The mechanics of hammer milling have been very well described by Ajayi and Clarke (1997). A screen size of 2 mm (WM) was used on the Thomas-Wiley laboratory mill (model 4, Arthur H. Thomas Co., Philadelphia, Penn., U.S.A.), and seeds were milled by the procedure described by Kerr et al. (2000).

A protocol was developed for milling using the plate mill (Model 4E, The Straub Co., Hartboro, Penn., U.S.A.). The clearance was varied on the plate mill by turning a screw in (for decreased clearance) or out (for increased clearance), thus affecting the distance between the two plates. The screw was turned all the way in and slowly unscrewed to calibrate before a milling run. The screw was marked and the angle of each turn measured and controlled. One full turn was designated to be 360°. The seed was milled at a clearance of 0 turn (PM-0), ¼ turn (PM-90), ½ turn (PM-180), ¾ turn (PM-270) and 1 turn (PM-360). Cowpea seeds were passed through the plate mill four times according to the milling protocol described in Table 2.1. The seeds and meals/flours were stored in sealed containers at 7 °C until used.

**Table 2.1.** Milling protocol for the plate mill at various clearances.

Sample	First Pass (Degrees out)	Second Pass (Degrees out)	Third Pass (Degrees out)	Fourth Pass (Degrees out)
PM-360	720	720	540	360
PM-270	720	540	360	270
PM-180	720	540	360	180
PM-90	720	540	360	90
PM-0	540	360	180	0

### *Preparing the pastes*

The pastes were prepared by adding a pre-determined amount of tap water to the meals. Wet mill (WTM) and PM-360 pastes were prepared to have 64% moisture. PM-270, PM-180, PM-90 and WM paste were adjusted to 62% moisture. PM-0 and HM-2.54 had 61% moisture content and HM-1.73 had 58% moisture. The selection of moisture content was based on the viscosity of whipped paste at various moisture contents with the WTM at 64% moisture content (Patterson et al., 2002) as the benchmark.

The WTM paste was prepared according to the method described by Patterson et al. (2002). Seeds were soaked for 3 hrs, chopped in a food chopper (Toledo chopper, Model 5120-0-009, Toledo, Ohio, U.S.A.) equipped with 2.84 mm opening disc, blended (Osterizer 12-speed blender, Sunbeam Corp., Milwaukee, Wis., U.S.A.) with the pre-determined amount of water for 5 minutes at high speed (stopping every minute to scrape the sides and blades of the blender) and whipped at speed 3 (high) (Hobart mixer, model N50, Hobart Corp., Troy, Ohio, U.S.A.) for another 1.5 minutes. Pastes from dry meals were prepared by adding the pre-determined amount of water to achieve the final paste

moisture described above, soaked for 15 minutes (before blending-BB), blended for 5 minutes (after blending-AB) and then whipped for 1.5 minutes (after whipping-AW).

The same appliances from the wet milling process as described above were used for the paste processed from dry meals. Each treatment (BB, AB, AW) was then tested for particle size distribution.

#### *Extraction of cellular material from meal*

The method developed by Reichert (1981) and modified by Kethireddipalli et al. (2002a,b) was used with minor modifications. Cowpea pastes were washed on a 400-mesh sieve by rubbing the paste for 12 minutes under running tap water. Rubbing of paste leads to removal of starch, proteins, and other soluble tissue remnants that are ingrained in the cellular matrix. The coarse material left on the sieve consists primarily of cell wall residue. This material absorbs moisture and enhances the water holding and swelling capacities of the pastes. The material was hand squeezed in a 351 polyester mesh (woven thermoplastic mesh, McMaster-Carr Supply Co., Atlanta, Ga., U.S.A.), to remove the excess moisture and then transferred to medium-sized sampling bags (Whirlpack bags, Fisher Scientific Ltd., Pittsburgh, Penn., U.S.A.). Thermocouples were inserted into the center of each sample, and the bags were left in a cryo-freezer until the temperature reached  $-40^{\circ}\text{C}$ . The sampling bags were left open and then transferred to a freeze drier until the material was dry. The bags were then stored in a desiccator until used.

#### *Dry particle sizing*

A sieve shaking method was used for dry particle size determination. Each milled sample was passed through a series of U.S. standard (ASTM specified) sieves (8, 10, 20,

30, 40, 50, 60, 100, 140 and 400 mesh screens) to separate it into fractions of various particle sizes. The pre-weighed sample (~500 g) was placed on the top sieve of the set of sieves and shaken with a sieve shaker (Model RX-86, W.S. Tyler, Mentor, Ohio, U.S.A.) until the weight of the material, on the smallest sieve, reached equilibrium. Equilibrium was determined by inspecting and weighing the bottom collection pan at 5-minute intervals after an initial shaking of 10 minutes. After reaching equilibrium, material on all sieves was weighed and recorded. In this experiment it was not possible to fit all of the sieves on the shaker at the same time. So, six larger-sized sieves and the bottom collection pan were used at first; the material on the bottom pan was then transferred onto the set of remaining smaller size sieves. All measurements were carried out in triplicate. ASAE Standard S319 (ASAE Standards, 1994) was used for calculating the geometric mean diameter ( $d_{gw}$ ) and geometric standard deviation of sample estimate ( $S_{gw}$ ). The following formulas were used to calculate  $d_{gw}$  and  $S_{gw}$ .

$$d_i = (d_i \cdot d_{i+1})^{1/2}$$

$$d_{gw} = \log^{-1} [\Sigma (W_i \log \bar{d}_i) / \Sigma W_i]$$

$$S_{gw} = \log^{-1} [\Sigma W_i (\log \bar{d}_i - \log d_{gw})^2 / \Sigma W_i]^{1/2}$$

Where

$d_i$  = diameter of sieve openings of the i'th sieve

$d_{i+1}$  = diameter of openings in next larger than i'th sieve (just above in a set)

$d_{gw}$  = geometric mean diameter

$\bar{d}_i$  = geometric mean diameter of particles on i'th sieve

$S_{gw}$  = geometric standard deviation

$W_i$  = weight fraction on the i'th sieve

$d_{0.5}$  is defined as the particle size at which 50% of the particles are held at the size indicated. It was calculated from the cumulative graph for BB (sieving data). The  $d_{0.5}$  for AB and AW was provided by the statistical package that came with the instrument installation software for Mastersizer S.

#### *Wet particle sizing*

Wet particle size distribution was determined by laser diffraction using a Mastersizer S (Malvern Instruments, Worcestershire, U.K.). This instrument requires particulate samples to be completely disassociated and suspended in a liquid. The measurement principle is based on simultaneous multi-angle detection of scattered light. Samples are passed through a He/Ne laser and the Malvern Mastersizer then calculates a size distribution from the raw light energy data using a statistical package (Rawle, 2001). The Mastersizer S detector array acquires light scattering data at the rate of 500 Hz (one measurement every 2 milliseconds) and the amount of light scattered is inversely proportional to the particle size of the material.

The refractive indices of the liquid and the sample are needed for the analysis. The presentation code is also needed for the calculation and was selected based on the particle refractive index. However, this information was not available for cowpea meal. The “wet standard presentation” was selected to represent the optical model of light scattering and used for calculating the particle size distribution of pastes. For measurement purposes, 1 g of sample was diluted in 100 mL deionized water. A disposable pipette was then used to introduce sample into a small volume presentation unit of the instrument, which already contained ~120 mL of deionized water, until the unit showed 13% obscuration level. Obscuration, the fraction of light lost from the main

beam when the sample is introduced, serves as an indication of overall particle concentration (Moughal et al., 2000). The unit pumped the sample through the optical cell by a stirrer that rotated at ~ 2100 rpm. The Malvern optical model calculates the relative volume distribution of particles and other size distribution parameters from the light scattering data assuming an equivalent sphere. Size distributions (volume fractions against particle size) were calculated. The data were also analyzed using ASAE standard S319.2 (ASAE Standards, 1994) to calculate  $d_{gw}$  and  $S_{gw}$ . All nine cowpea samples and their corresponding three treatments (BB, AB and AW) were subjected to the wet particle size distribution measurements. The measurements were carried out in triplicate.

#### *Water holding capacity*

Water holding capacity (WHC) of the freeze-dried material was measured by using the filtration method developed by Robertson and Eastwood (1981) with minor modifications. Freeze-dried material (0.3 to 0.5g) was measured and transferred to a tared 20 mL screw cap test tube. Deionized water (20 mL) was added to the test tube and vortexed for 1 minute at high speed (Vortex-Genie, Fisher Scientific Industries, Bohemia, N.Y., U.S.A.) and then allowed to hydrate for 24 h at 2 °C. After the hydration period, the material was gravity filtered through a pre-saturated Whatman No. 1 filter paper for 1h at room temperature. The filtering samples were covered with plastic wrap to prevent moisture losses to evaporation during filtration. The sample after filtration was weighed, dried, and reweighed. The sample was dried in a vacuum oven for 18h at 70 °C and ~ 25 mm Hg vacuum. WHC was expressed as grams of water held/gram of the dry material. Three replications for each sample and the corresponding treatment were carried out.

### *Swelling capacity*

Swelling capacity (SWC) of the samples was analyzed by the bed volume technique after equilibrating in an excess amount of deionized water (Kuniak and Marchessault, 1972). Deionized water (10 mL) was added to 0.1 g of sample in a 10 mL graduated cylinder and the mixtures were then vigorously stirred. The graduated cylinder was left to stand at room temperature (25° C) for 24 h. Swelling capacity was measured and expressed as milliliters of swollen sample per gram of sample (dry weight). Triplicate measurements were taken for all nine samples and corresponding three treatments.

### *Statistical analysis*

The analysis of variance (ANOVA) procedures were used to analyze all data (SAS, 2002). Mean separation was performed by the LSD test ( $\alpha = 0.05$ ).

## Results and Discussion

### *Dry milling and sieve analysis*

Results from particle size distribution as determined by sieve shaking are shown in Table 2.2. Seeds milled through the plate mill with clearance of 360, 270, 180 and 90 degrees showed a high percentage of large-sized particles. Particles in these samples were mainly concentrated on the first three sieve sizes (8, 10, and 20-mesh). As the clearance decreased, particle size tended to shift towards the lower (smaller-sized) sieves. PM-360 had approximately 69.70% particles larger than 8-mesh. The next two sieve sizes had 11.87 and 12.83% of the total particles, respectively. The first three sieves held 94% of the total meal particles. Further down the sieves, the percentage of particles showed a sharp decrease.

Sample PM-270 showed a similar trend as PM-360; however, the particle size distribution in this case was more evenly distributed among the first three sieves. The first three sieves (8, 10 and 20-mesh) held 37.37, 20.12 and 33.31% meal particles, respectively, which accounted for 90.8% of the total; 6.08% of the remaining was primarily held on next three sieves (30, 40 and 50-mesh). PM-180 showed a greater distribution of particles on lower sieves. The first three sieves held 21.23, 16.67 and 48.57% of the total meal particles. Confirming the trend seen in PM-360 and PM-270, the third sieve (20-mesh) showed a further increase in meal particles. The next three sieves held another 9.34% of the total; only 4.17% of the total was held on finer sieves. Further decreasing the clearance with PM-90, 9.92, 11.59 and 58.06% of the particles were held on the first three sieves (8, 10 and 20-mesh), respectively. There was a further decrease of approximately 5% total particles on the first three sieves, as compared to the

previous sample (PM-180). The 20-mesh sieve showed a further increase in meal content (58.06% vs 48.57%) as compared with PM-180; 20.43% of the total meal was distributed on the remaining seven sieves.

PM-0 was the finest flour among the plate-milled samples. The first two sieves (8 and 10-mesh) held only 1.12% of the total meal particles. Particle distribution was concentrated on the next four sieves (20, 30, 40 and 50-mesh) and accounted for 79.95% of the total particles. The increase in finer-sized particles is very notable here. This confirms the expected trend of smaller particle size with decreasing clearance.

HM-1.73 produced the finest millings with the first two sieves holding only 1.50% of the particles. This was expected since the screen size is 1.73 mm and the milled material has to be less than 2 mm (10-mesh). The 20-mesh sieve held 4.35% of the total particles. The next three sieves (30, 40 and 50-mesh) held 15.69, 19.90 and 22.34% of the meal particles, respectively. The last four sieves (60, 100, 140 and 400-mesh) held a total of 35.97% meal particles. Among all of the samples, this was the largest amount held on the finer sieves. Visually, the sample was very powdery and tended to be lost in the air during milling. HM-2.54 held a slightly higher amount (1.70%) on the first two sieves (8 and 10-mesh). The third sieve (20-mesh) held a large (37.12%) amount of particles. The next three sieves (30, 40 and 50-mesh) held 18.76, 13.09 and 9.03% meal particles, respectively. The finer sieves (60, 100, 140 and 400-mesh) held 20.19%.

The Wiley mill showed a low (0.68%) volume of particles on the first two sieves (8 and 10-mesh). The third sieve (20-mesh) held a large (54.06%) volume of meal particles. The 30-mesh sieve recorded 18.65% of the total, and 72.71% of the total

particles were present on these two screens. The finer sieves (60-400 mesh) held a total of 11.22% of the total particles.

Large cowpea particle size has been reported to produce better *akara* than small particles (Ngoddy et al., 1986; McWatters, 1983). Ngoddy et al. (1986) recommended that flours used for *akara* and *moin-moin* be milled with 65-75% of the particles in the 350 to 100-mesh size range. In our study, HM-1.73 had 27.14% of its particles in the 400 to 100-mesh size range. This was the highest amount of particle concentration among all samples retained on the mentioned sieve sizes. McWatters (1983) found that wet-milled paste had a larger average particle size than paste made from meal and hence produced better quality *akara*. Traditionally wet-milled paste had 42% of its particles retained on the 100-mesh sieve whereas the meal had only 13% on the same screen. Particles from a commercial Nigerian flour were mostly found to be concentrated on the 400-mesh (47.53%) sieve (McWatters, 1983). Kethireddipalli et al. (2002a) reported that *akara* produced from unblended fine flour was dense and had a less spongy texture than its wet-milled counterpart. It was suggested that adverse functionality of dry flour was due to intense dry milling and the resultant small particle size that also affected its *akara*-making quality.

Figure 2.1 shows plots of volume percent of particles suspended in water over a range of particle diameter as determined by light-scattering analysis. Critical parameters describing all curves are shown in Table 2.3, and include total volume percent of particles under given peaks (peak 1 and peak 2), particle size at maximum volume percent ( $dm_1$  and  $dm_2$ ) and size at which peak 1 ends (ends at). By following the changes in mode of peak 1 and peak 2 ( $dm_1$  and  $dm_2$ ), % volume of particles under peak 1 and peak 2, we can

monitor the shift in particle concentration after each treatment (BB, AB and AW). The samples with larger mean particle size showed lesser volume of particles under peak 1 (BB in Table 2.3), whereas the smaller particle samples show almost all their particles under the first peak. Log-log plots for PM-360, PM-270, PM-180 and PM-90 showed a bimodal distribution (Figure 2.1 a, b, c, d). The bimodal samples showed less than 100% particles under peak 1. This is not very well illustrated on the corresponding plots because the particle size data are not very well distributed. This is due to the limitation of number of sieves that can be practically used. It was noted that samples from PM-0, HM-1.73, HM-2.54 and WM showed ~100% of their particles under peak 1 and their log-log plots (Table 2.3) were monomodal in nature (Figure 2.1e, f, g, h). This is also affirmed by the  $dm_1$  and peak 1 data.

The average geometric mean diameter ( $d_{gw}$ ) by mass for all samples (in mm) is shown in Table 2.4. The trend seen in  $d_{gw}$  values is apparent in plots of the dry sieving data. The lower  $dm_1$  also serves as an indicator of smaller particle size. HM-1.73 had a  $dm_1$  of 297 microns (Table 2.3) and was monomodal. It also had the lowest  $d_{gw}$ . Before blending (BB), PM-360 had the lowest volume of particles under peak 1 (30.3%)(Table 2.3). Since 69.7% of the particles fell under peak 2, the sample was large in size with a large  $d_{gw}$ .

PM-360 had the largest  $d_{gw}$  (1558.6 microns) among all samples (Table 2.4). This was in accordance with the sieving data. Since most of the particles were concentrated on larger-sized sieves, a larger mean diameter was expected. PM-360 was followed by PM-270 (1103.2 microns), PM-180 (864.6 microns), PM-90 (693.3 microns), WM (482 microns), HM-2.54 (359.9 microns), PM-0 (357.9 microns) and HM-1.73 (221.1

microns). Since HM-1.73 had the highest concentration of particles on finer screens, the  $d_{gw}$  is the lowest. The  $d_{gw}$  values for all samples except PM-0 and HM-2.54 were significantly different.

Another way to evaluate the particle size distribution is to plot the cumulative size distribution. Figure 2.2 shows the cumulative graph; perpendicular lines have been drawn to indicate the particle size at which 50% of the total particles were held ( $d_{0.5}$ ). The  $d_{0.5}$  values are also stated in Table 2.4. PM-360 had 50% of its particles larger than 2180 microns. HM-1.73 had the finest particles with 50% of the particles larger than 280 microns. The order of size at which 50% of particles were present follows the same order as  $d_{gw}$  values (Table 2.4). The  $d_{0.5}$  value is not an absolute value and will be influenced accordingly if a different model was used to plot the cumulative data.

**Table 2.2.** Dry particle size measurements of cowpeas milled from eight different samples (in percentage material on each screen).<sup>1</sup>

US Standard Sieve No.	Nominal Sieve Opening (mm)	Plate mill PM-360	Plate mill PM-270	Plate mill PM-180	Plate mill PM-90	Plate mill PM-0	Hammer mill 2.54 mm HM-2.54	Hammer mill 1.73 mm HM-1.73	Wiley mill 2 mm WM
8	2.36	69.70	37.37	21.23	9.92	0.49	0.47	0.63	0.37
10	2	11.87	20.12	16.67	11.59	0.63	1.23	0.87	0.31
20	0.841	12.83	33.31	48.57	58.06	22.59	37.12	4.35	54.06
30	0.595	1.53	3.02	4.23	6.74	25.09	18.76	15.69	18.65
40	0.42	1.19	2.04	2.88	4.25	18.94	13.09	19.90	4.38
50	0.297	0.70	1.02	2.23	3.77	13.33	9.03	22.34	9.25
60	0.25	0.35	0.38	0.94	1.28	7.45	4.56	8.83	3.25
100	0.15	0.96	1.62	1.47	2.24	5.39	6.78	11.24	6.16
140	0.105	0.51	0.64	1.20	1.00	4.49	6.26	7.93	1.32
400	0.038	0.37	0.50	0.56	1.15	1.58	2.59	7.97	0.49

<sup>1</sup> PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill).

**Table 2.3.** Percent particles under peak 1,  $dm_1$  (mode of peak 1), end point,  $dm_2$  and volume under peak 2 for all samples and their corresponding treatments as determined by sieving (BB) and laser diffraction (AB and AW).<sup>1</sup>

Sample	BB			AB					AW				
	Peak 1 (Percent particles)	$dm_1$ (microns)	Peak 2 (Percent particles)	Peak 1 (Percent particles)	$dm_1$ (microns)	Ends at (microns)	$dm_2$ (microns)	Peak 2 (Percent particles)	Peak 1 (Percent particles)	$dm_1$ (microns)	Ends at (microns)	$dm_2$ (microns)	Peak 2 (Percent particles)
WTM <sup>2</sup>	14.34	20.42	85.64	16.90	20.42	59.84	689.01	83.10	18.82	20.42	65.99	689.01	81.18
PM-360	30.31	841	69.69	17.86	20.42	59.84	466.05	82.14	17.19	20.42	59.84	513.90	82.81
PM-270	62.65	841	37.35	17.47	20.42	59.84	513.90	82.53	17.60	20.42	59.84	513.90	82.40
PM-180	78.75	841	21.25	18.64	20.42	59.84	466.05	81.36	19.01	20.42	59.84	466.05	80.99
PM-90	90.08	841	9.92	17.21	20.42	59.84	566.67	82.79	18.35	20.42	59.84	566.67	81.65
PM-0	99.98	595	0.02	23.53	20.42	65.99	466.05	76.47	22.28	22.52	72.76	422.65	77.72
HM-2.54	100	841	...	20.10	20.42	59.84	513.90	79.90	19.61	20.42	59.84	466.05	80.39
HM-1.73	100	297	...	22.32	20.42	59.84	466.05	77.68	20.21	20.42	59.84	466.05	79.79
WM	100	841	...	23.49	20.42	65.99	466.05	76.51	20.14	20.42	65.99	513.90	79.86

<sup>1</sup>BB (before blending), AB (after blending), AW (after whipping); peak 1 and peak 2: Volume % of sample particles held under peak 1 and peak 2, respectively;  $dm_1$  and  $dm_2$ : Mode of peak 1 and peak 2, respectively; WTM (wet milled), PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill).

<sup>2</sup>WTM BB values are derived from laser diffraction data whereas all other BB values are from sieve shaking data.

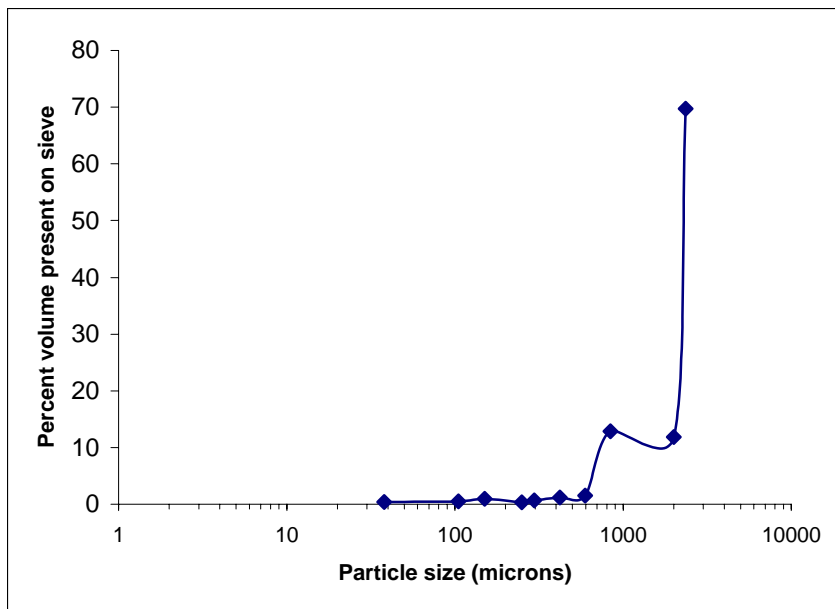


Fig. 2.1(a): Sieve shaking measurement for PM-360

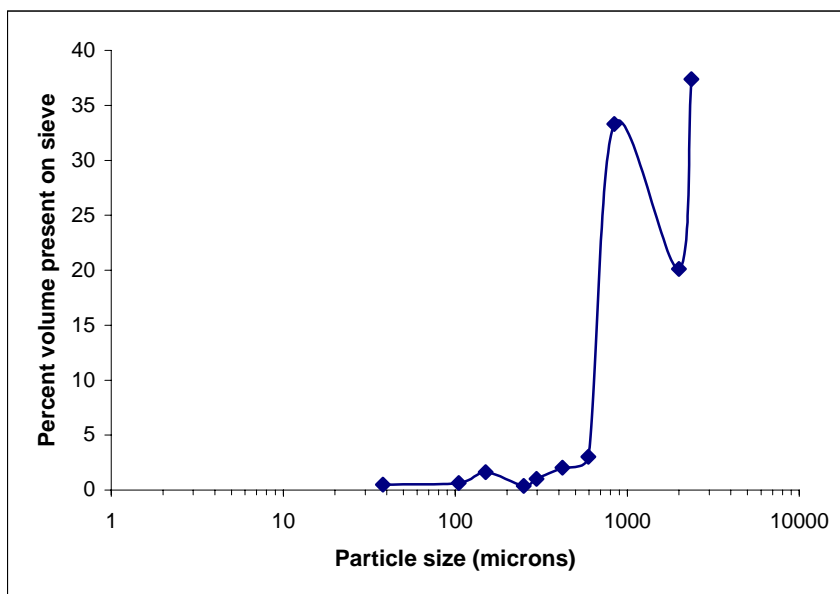


Fig. 2.1 (b): Sieve shaking measurement for PM-270

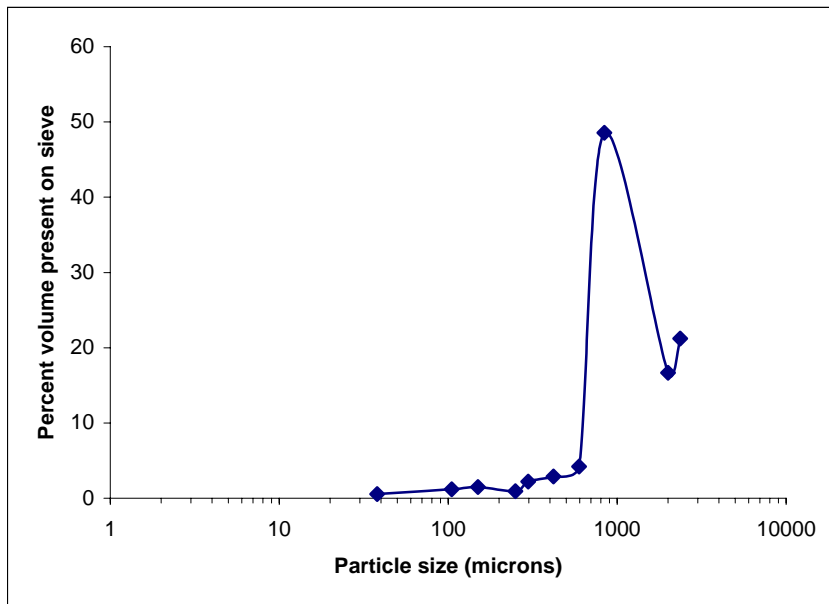


Fig. 2.1 (c): Sieve shaking measurement for PM-180

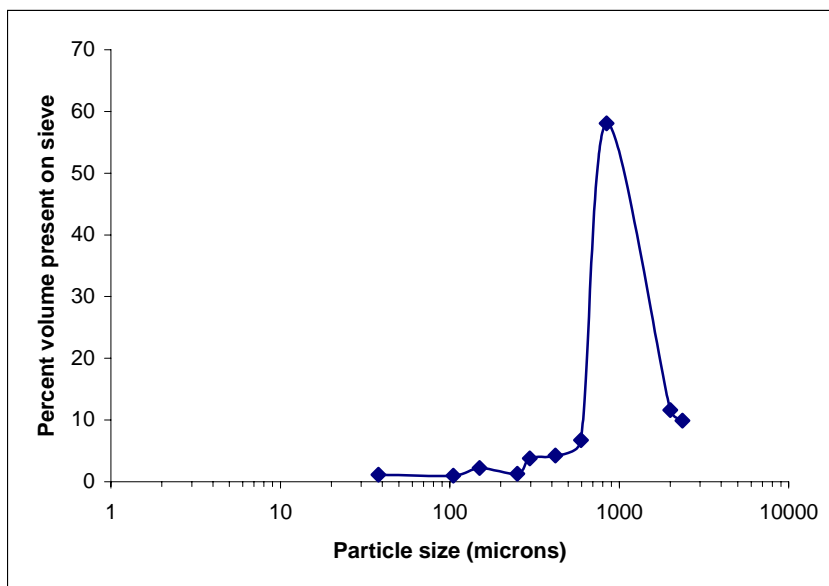


Fig. 2.1 (d): Sieve shaking measurement for PM-90

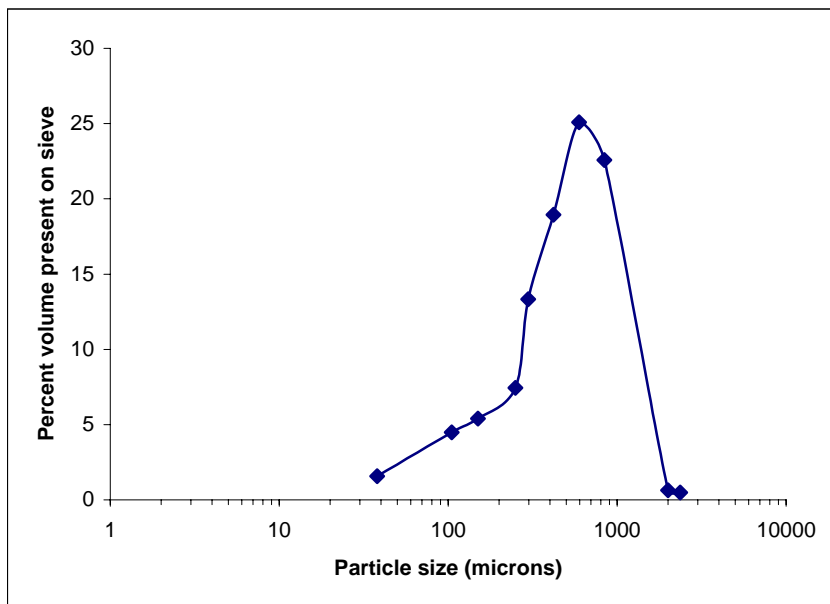


Fig. 2.1 (e): Sieve shaking measurement for PM-0

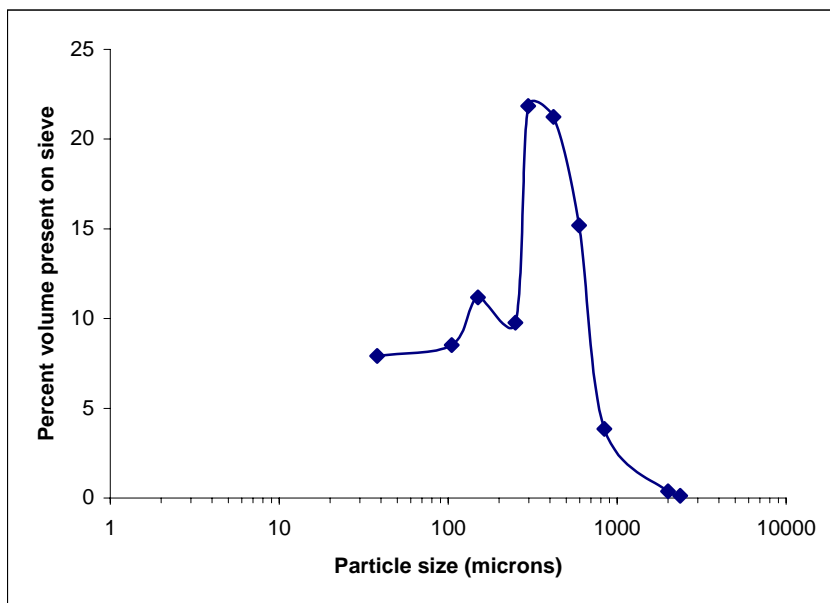


Fig. 2.1 (f): Sieve shaking measurement for HM-1.73

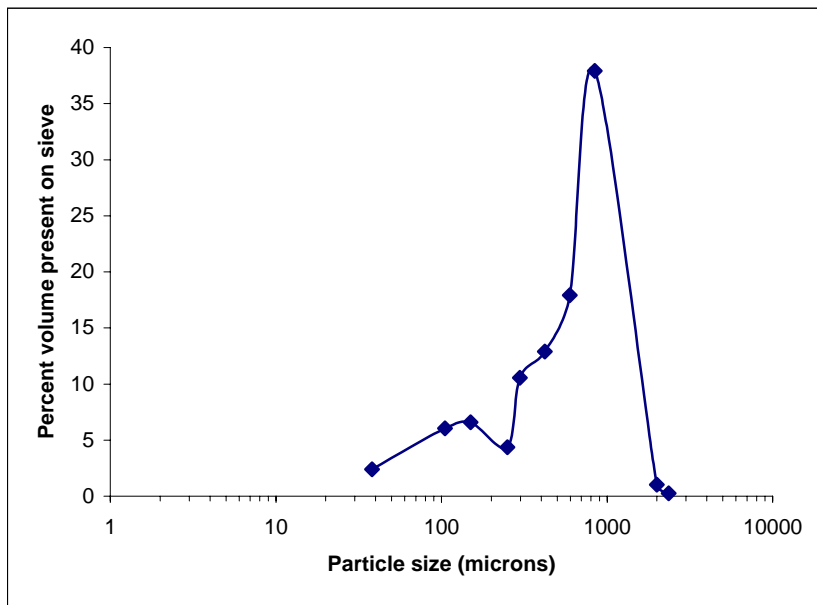


Fig. 2.1 (g): Sieve shaking measurement for HM-2.54

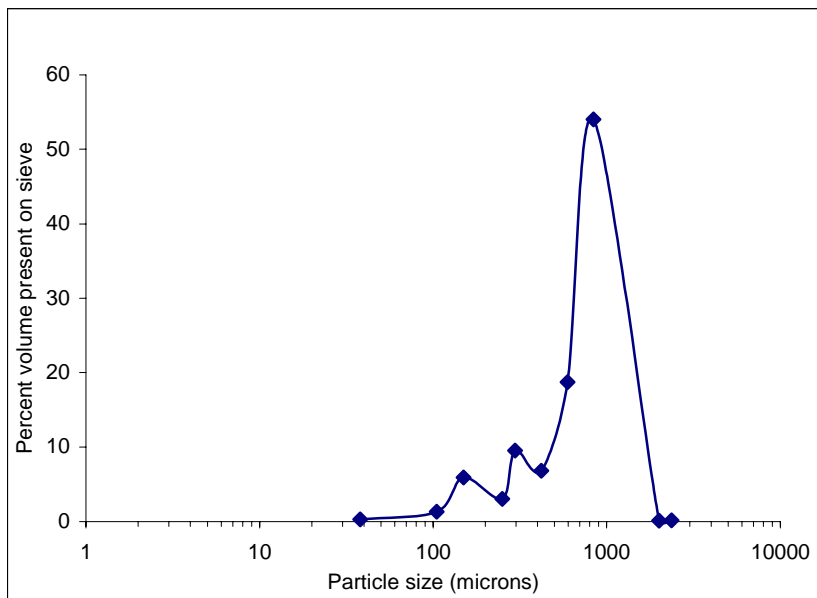
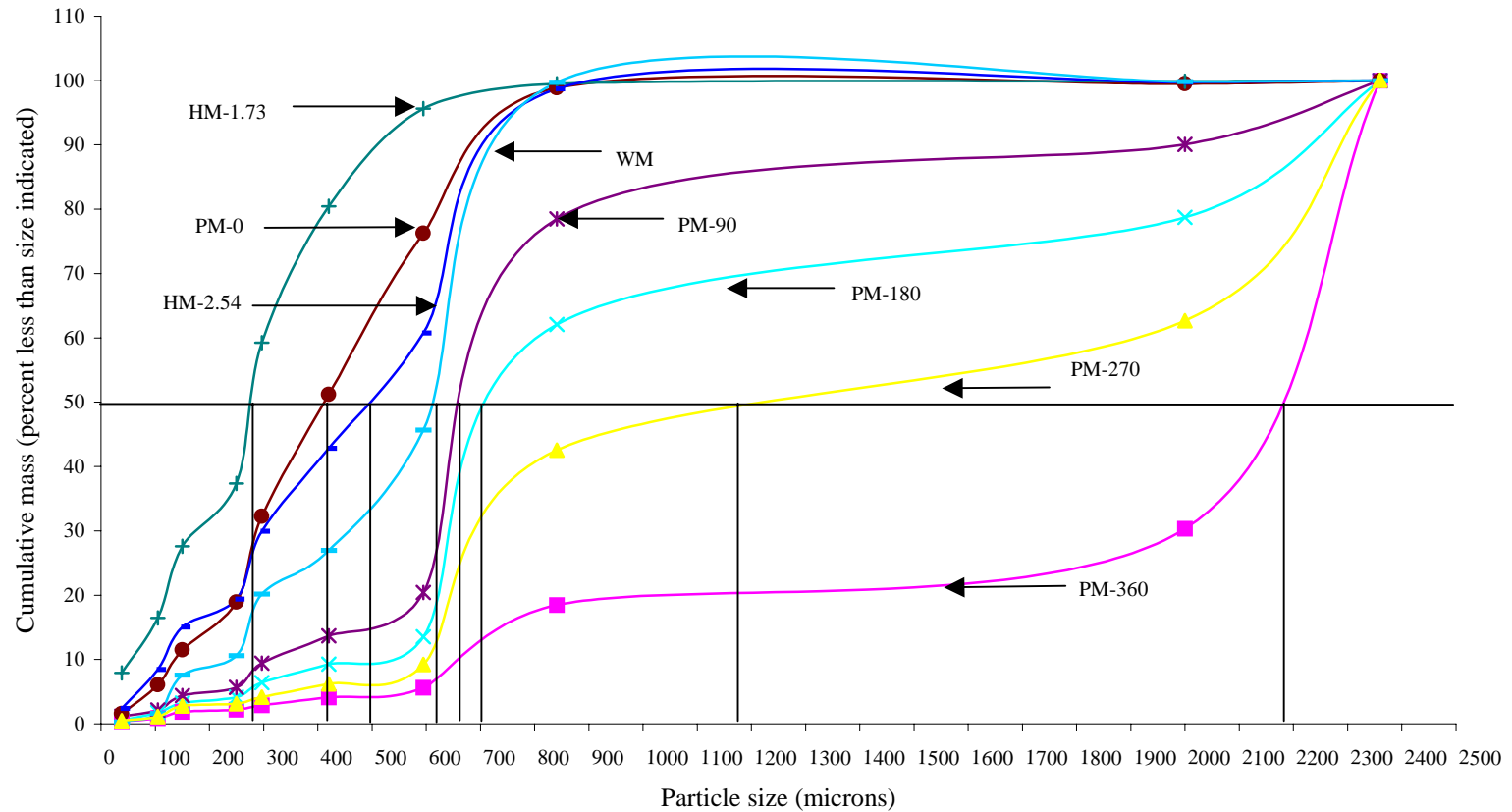


Fig. 2.1 (h): Sieve shaking measurement for WM

**Table 2.4.** Size measurements of cowpea meal samples as measured by sieve shaking.<sup>1</sup>

Size	PM-360	PM-270	PM-180	PM-90	PM-0	HM-2.54	HM-1.73	WM
$d_{gw}$ (microns)	1558.6a <i>(2.1)</i>	1103.2b <i>(2.0)</i>	864.6c <i>(2.0)</i>	693.3d <i>(2.0)</i>	357.9f <i>(2.2)</i>	359.9 <i>(1.8)</i>	221.1g <i>(2.2)</i>	482.0e <i>(1.9)</i>
$d_{0.5}$ (microns)	2180	1180	720	640	420	500	280	620

<sup>1</sup> a, b, c, d, e, f, g: Mean values in a row not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill); The  $S_{gw}$  (geometric standard deviation of sample estimate) values are italicized and in parentheses below the corresponding  $d_{gw}$ .



**Figure 2.2.** Sieve analysis for cowpea meal/flour milled in different mills; PM (Plate milled samples are followed by the number of degrees of clearance); HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill)

### *Wet particle sizing*

Samples from three different treatments (BB, AB and AW), and their particle size distributions were determined by a Mastersizer S. Mastersizer S had some limitations regarding the size distribution it could determine. The lens used had an upper range of 837 microns. As is evident from the dry sieving results (Table 2.2), the particle sizes ranged up to 2300 microns (PM-360). Therefore, the values calculated for BB were not considered to be precise and representative of the sample. Also, the sample size for the Mastersizer was very small (1 g out of 210 - 248g paste, depending on the sample and then diluted 1200 times), so the presence or absence of a single large particle can affect the data considerably. The dry sieving results for BB were used instead of wet BB results for better comparison because there is no size limitations with sieves used. An exception was made for the control, since it was not dry milled. Wet particle size results discussed here are for AB and AW only.

The control (WTM) showed a  $d_{gw}$  of 292.0 microns before blending (BB) (Table 2.5). With further blending (AB) and whipping (AW), the  $d_{gw}$  was reduced to 253.0 and 236.5 microns, respectively. The major size reduction occurred in the step of additional blending. There was 13.36% reduction in size between BB and AB and a further reduction of 6.51% after whipping (AW);  $d_{gw}$  increased with the increase in clearance and screen size. PM-360 showed the largest reduction (88%) in particle size between BB and AB followed by PM-270, PM-180, PM-90, WM, PM-0 and HM-2.54. Other than the control, HM-1.73 showed the least particle size reduction of 24.06%. WTM had the largest  $d_{gw}$  (236.5 microns) for AB. HM-1.73, HM-2.54, PM-0 and WM were not significantly different in  $d_{gw}$  and were the smallest.

In addition to incorporating air into the sample, whipping (AW) had no significant affect on the particle size distribution of all samples. AW from WTM and PM-90 showed a positive reduction of 6.51 and 8.36% over AB, respectively. PM-270, PM-180 and HM-2.54 showed little reduction in size after whipping (AW). However, PM-360 (-4.32%), PM-0 (-1.25%), HM-1.73 (-8.81%) and WM (-15.49%) showed the opposite trend. This was probably due to particle aggregation. Some researchers reported aggregation due to agitation in the case of fine powders (Irmouli and Haluk, 2002). Aggregated particles have a larger mean particle size due to increased surface area.

The effect of different treatments on the particle size of samples is very evident from the results obtained from this experiment. Additional blending (AB) played the most important role in particle size reduction. Blending reduced the particle size from a vast range in BB (1558 to 221 microns) to a limited range in AB (166 to 252 microns). It can be concluded that the time of blending is another factor that determines the particle size distribution. Whipping (AW) did not show any significant effect in particle size reduction when compared to AB.

Figure 2.3 shows the plots for particle size for all samples (AB and AW), as determined by Mastersizer S. The individual sample curves in conjunction with dry BB curves (Figure 2.1) show a definite shift in particle size distribution, confirming the trend in  $d_{gw}$  values. The modes ( $dm_1$  and  $dm_2$ ) and volume under peak1 demonstrate the bimodal nature of AB and AW curves (Table 2.3). For all cowpea samples,  $dm_1$  decreased significantly in AB and AW from BB. This illustrates the shift of particles from higher to lower sizes.

Cumulative plots show the relationship between AB and AW (Figure 2.4 and 2.5, respectively) in which the effect of blending is very clear as the particle size is reduced significantly. The curves tend to merge for AB and AW, indicating similar particle size distribution. Perpendicular lines have been drawn to the particle size at which 50% ( $d_{0.5}$ ) of the total particles were held. The samples with higher particle size for 50% cumulative mass of particles were the larger-sized samples. WTM had 50% of its particles at 477 microns after AW (Table 2.6), and PM-0 had the lowest at 302 microns. The order of size at which 50% of particles were present is in accordance with the  $d_{gw}$  values (Table 2.5).

The smaller particles are most likely suspended starch granules, while the larger particles correspond to gritty, undissociated meal particles (Kerr et al., 2000). The sample with the nearest mean particle size to WTM after whipping was PM-360. This is significant because whipping is the final step in the preparation of the paste and the condition of particle size after this step is crucial in determining the final paste functionality and product quality.

**Table 2.5.** Geometric mean diameter ( $d_{gw}$ ) and geometric standard deviation ( $S_{gw}$ ) of flour/meal particles as measured by sieve shaking (BB) and laser diffraction (AB, AW).<sup>1</sup>

Sample	BB	AB	AW	% Change (BB to AB)	% Change (AB to AW)
WTM	292.0 <sup>2</sup> <i>fg</i> (3.81)	253.0a (4.00)	236.5a (4.22)	13.36	6.51
PM-360	1558.6a (2.04)	196.5bc (3.97)	205.0b (3.85)	87.40	-4.32
PM-270	1103.2b (2.04)	207.3bc (3.95)	199.0b (3.93)	81.16	4.00
PM-180	864.6c (1.99)	199.9bc (4.02)	192.1bc (4.01)	76.76	3.89
PM-90	693.3d (1.99)	217.0ab (3.95)	198.9b (3.85)	68.54	8.36
PM-0	359.9f (2.20)	166.7c (4.37)	168.8c (4.09)	53.69	-1.25
HM-2.54	376.7f (1.77)	183.4bc (4.25)	181.1bc (4.67)	51.73	1.25
HM-1.73	221.1g (2.20)	167.1c (4.30)	181.8bc (4.09)	24.06	-8.81
WM	482.0e (1.89)	169.0c (4.38)	195.2b (4.10)	64.79	-15.49

<sup>1</sup> a, b, c, d, e: Mean values in a column not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); WTM (wet milled), PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill); The  $S_{gw}$  (geometric standard deviation of sample estimate) values are italicized and in parentheses below the corresponding  $d_{gw}$ .

<sup>2</sup> WTM BB values are derived from laser diffraction data whereas all other BB values are derived from sieve shaking data.

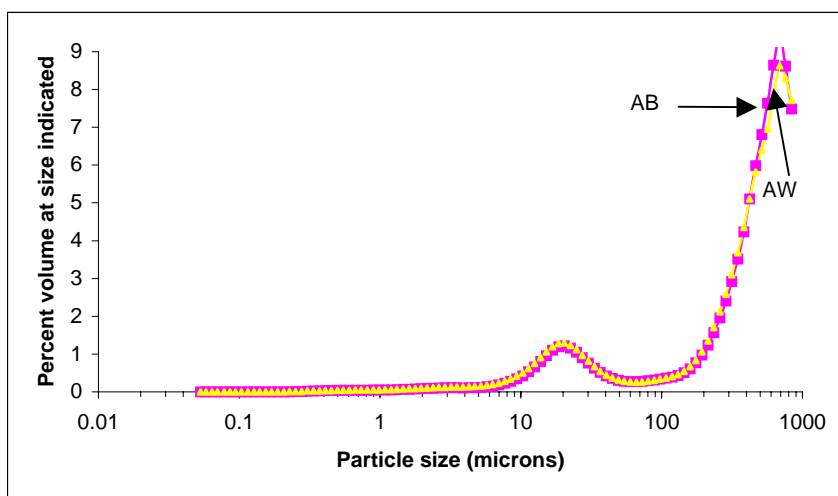


Fig. 2.3(a). Laser diffraction measurements for WTM; AB = after blending; AW = after whipping.

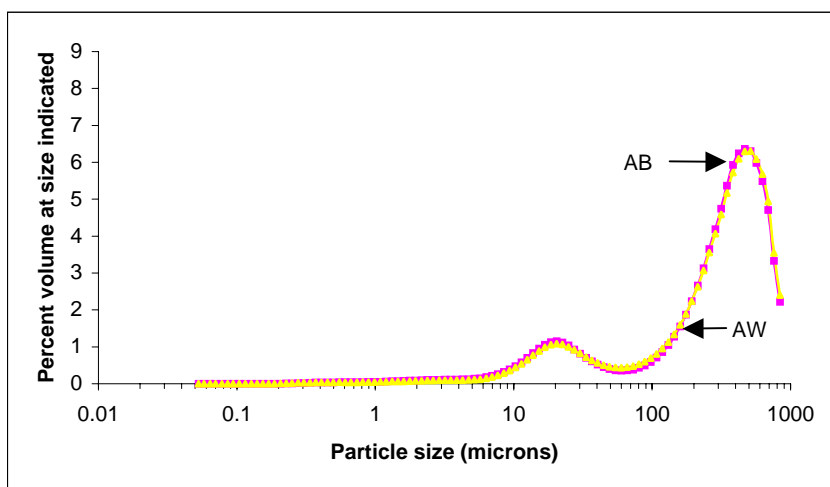


Fig. 2.3(b). Laser diffraction measurements for PM-360; AB = after blending; AW = after whipping.

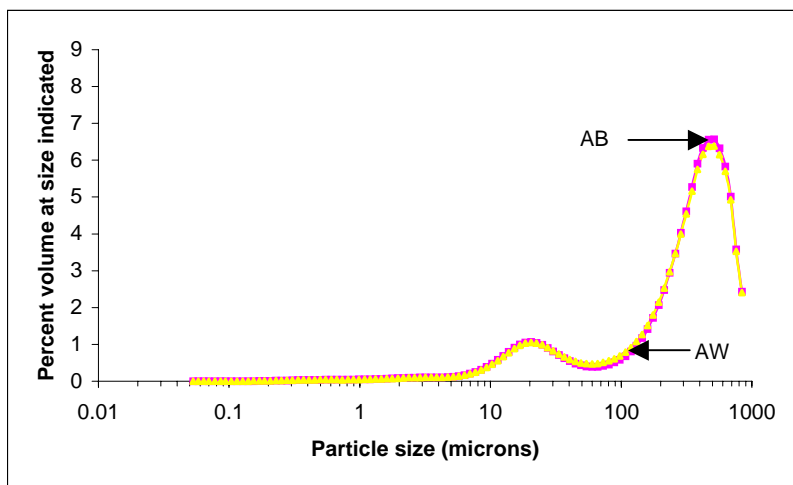


Fig. 2.3 (c). Laser diffraction measurements for PM-270; AB = after blending; AW = after whipping.

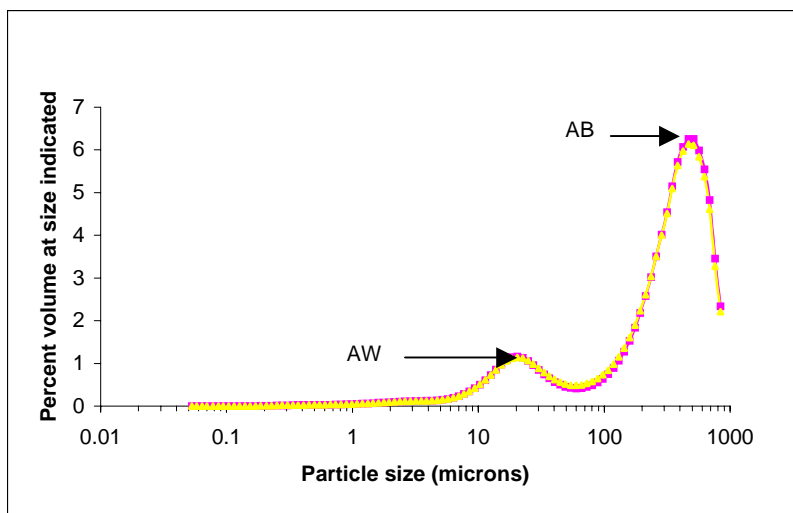


Fig. 2.3 (d). Laser diffraction measurements for PM-180; AB = after blending; AW = after whipping.

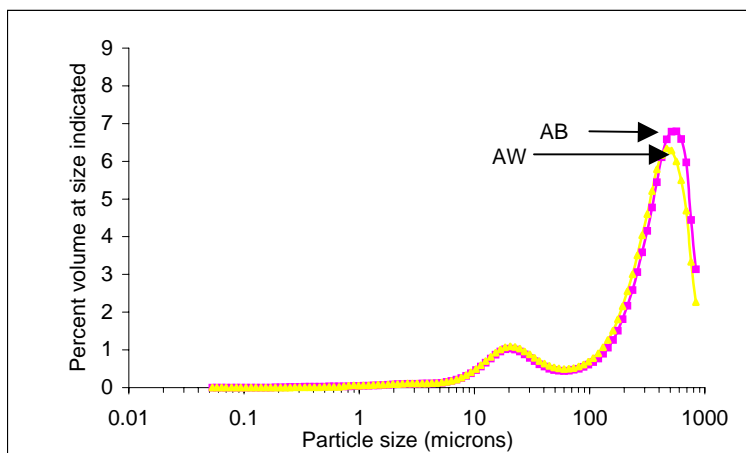


Fig. 2.3 (e). Laser diffraction measurements for PM-90; AB = after blending; AW = after whipping.

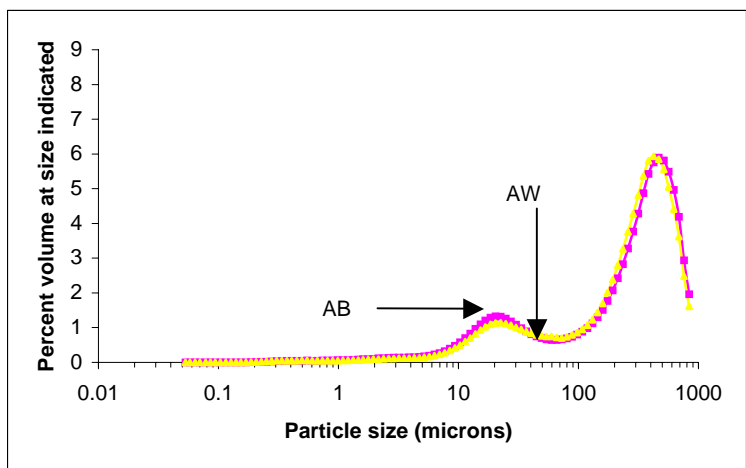


Fig.2.3 (f). Laser diffraction measurements for PM-0; AB = after blending; AW = after whipping.

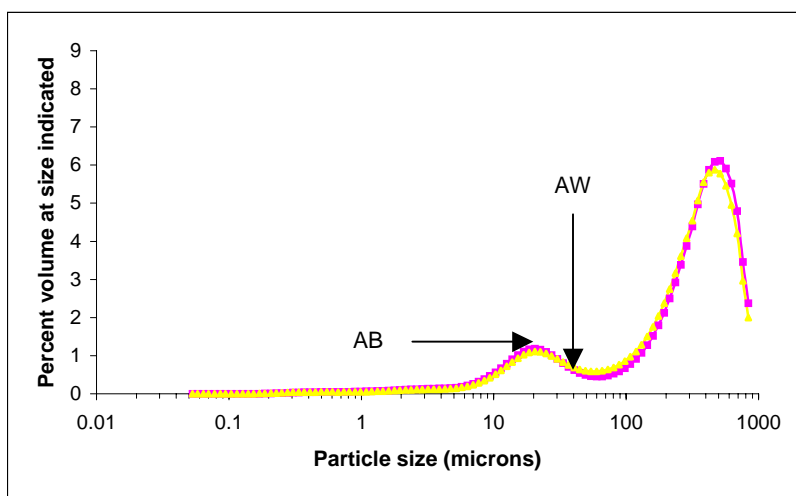


Fig.2.3 (g). Laser diffraction measurements for HM-2.54; AB = after blending; AW = after whipping.

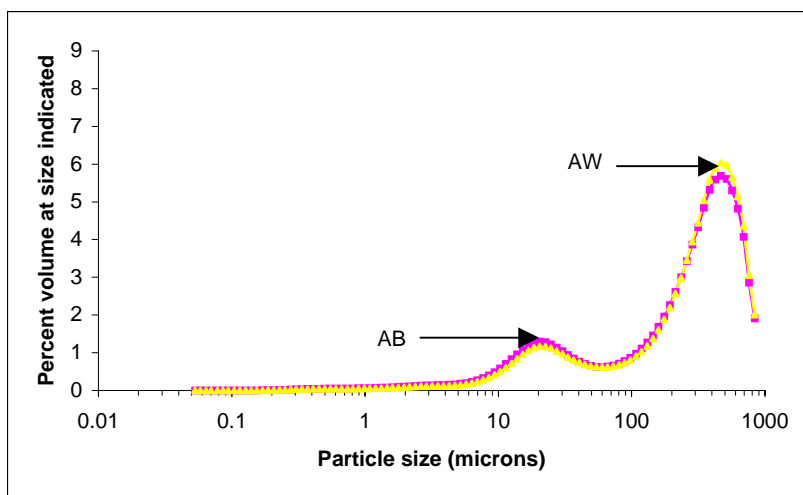


Fig. 2.3 (h). Laser diffraction measurements for HM-1.73; AB = after blending; AW = after whipping.

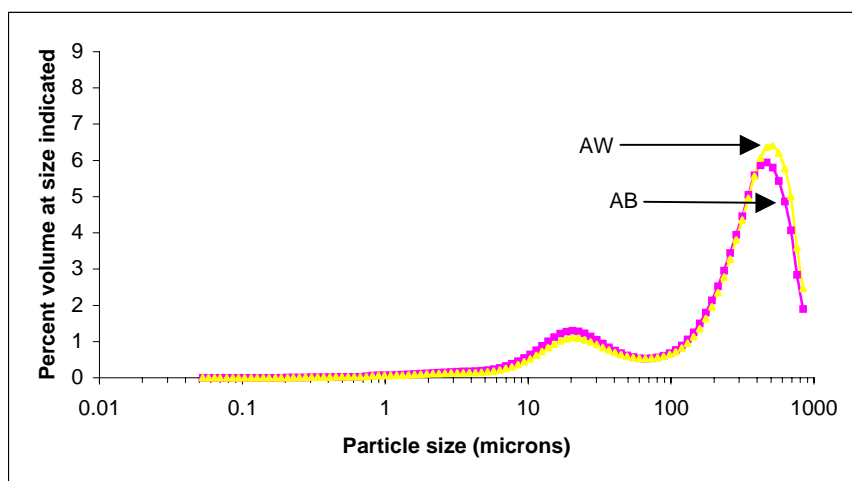
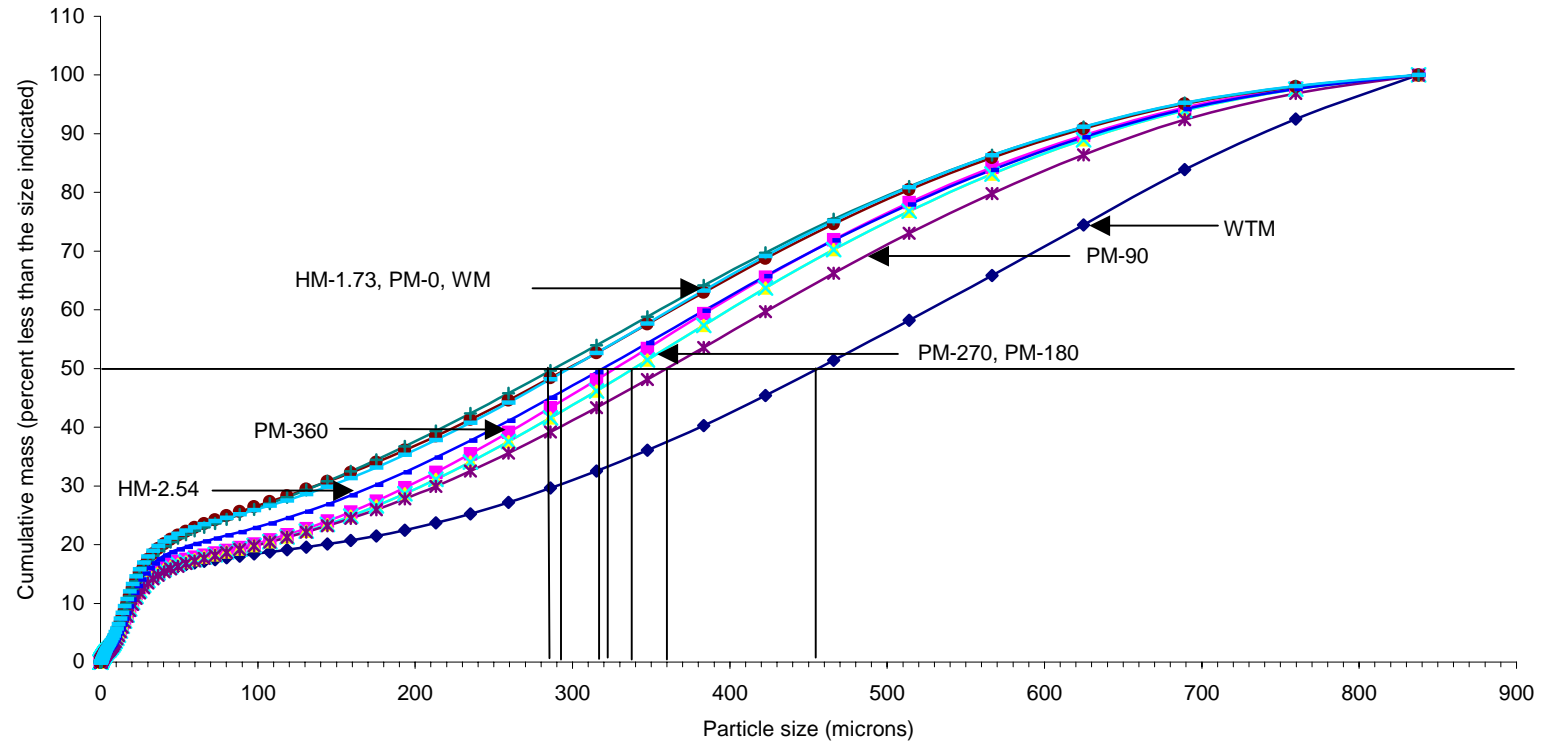
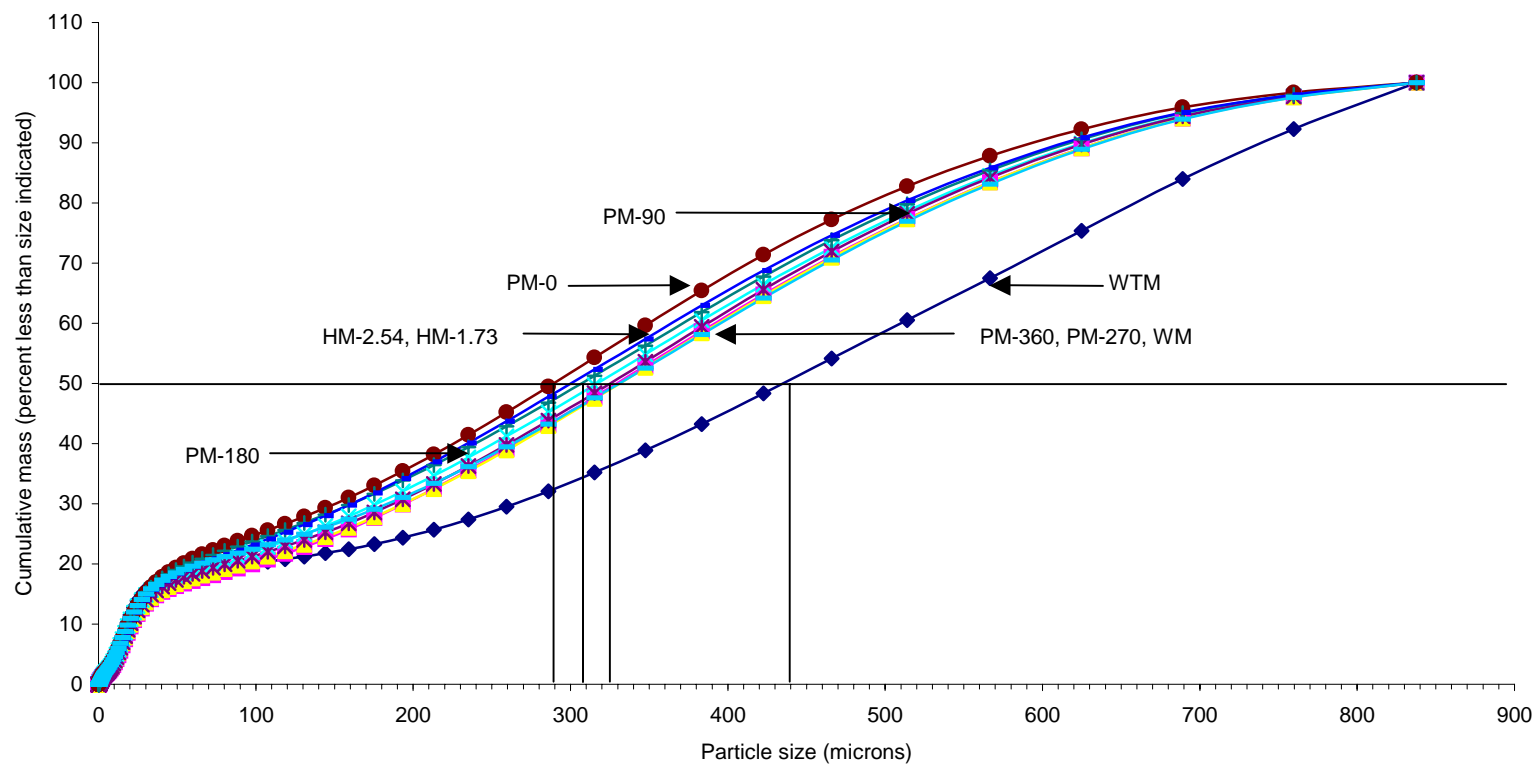


Fig. 2.3 (i). Laser diffraction measurements for WM; AB = after blending; AW = after whipping.



**Figure 2.4.** Cumulative plot of all mills for After Blending (AB) as measured by laser diffraction; WTM (Wet milled); PM (Plate milled samples are followed by the number of degrees of clearance); HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill)



**Figure 2.5.** Cumulative plot of all mills after whipping (AW) as measured by laser diffraction; WTM (Wet milled); PM (Plate milled samples are followed by the number of degrees of clearance); HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill)

**Table 2.6.**  $d_{0.5}$  values for sieve shaking (BB) and laser diffraction (AB and AW).<sup>1</sup>

Sample	BB (microns)	AB (microns)	AW (microns)
WTM	630 <sup>2</sup>	487	477
PM-360	2180	344	346
PM-270	1180	355	348
PM-180	720	342	333
PM-90	640	378	341
PM-0	420	311	302
HM-2.54	500	334	315
HM-1.73	280	303	322
WM	620	314	348

<sup>1</sup> BB (before blending), AB (after blending), AW (after whipping); WTM (wet milled), PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill).

<sup>2</sup>WTM BB value is derived from laser diffraction data whereas all other BB values are derived from sieve shaking data.

### *Water holding capacity*

Data on WHC for all samples and treatments are shown in Table 2.7.

Statistical analysis of water holding capacity results showed some significant differences between samples after blending (AB). HM-2.54 had the lowest WHC after blending (AB) and was significantly different from all other treatments.

The control (WTM) had the highest WHC for BB (12.12 g/g), followed by HM-1.73 (8.44 g/g), HM-2.54 (6.38 g/g), PM-0 (6.21 g/g), WM (5.35 g/g), PM-90 (5.32 g/g), PM-180 (4.93 g/g), PM-270 (4.74 g/g) and PM-360 (4.32 g/g). Looking at the mean particle size data for BB (Table 2.4), we can see the clear trend of decreasing WHC with increasing particle size. This can be explained by the lack of fibrous cellular wall material in the meal of these larger particle-sized samples. Samples produced by larger-sized screens and clearances generate meal, which has a negligible amount of fibrous cell wall material. It is mostly large particles of partially broken cotyledons. These particles fail to absorb a lot of moisture because they still have intact cells. WTM shows a high WHC because the sample has already been soaked and chopped. This leads to an increased amount of cell wall material in the solution, which in turn results in a higher WHC. Fine flours like HM-1.73 show a high WHC due to increased surface area as a result of intense milling. Similar findings have been reported by Kethireddipalli et al. (2002b). Auffret et al. (1994) found that the smaller the particle size, the faster the initial rate of absorption.

WHC was greatly improved in all samples after the next treatment (AB). PM-180 had the highest WHC of 18.05 g/g followed by PM-90 (18.04 g/g), PM-360 (17.95 g/g), WTM (17.50 g/g), PM-270 (17.31 g/g), PM-0 (16.95 g/g), HM-1.73

(16.00 g/g), WM (15.27 g/g) and HM-2.54 (14.33 g/g). PM-360 showed the largest increase (315.51%) in WHC between BB and AB. It was followed by other samples with large average particle sizes. WTM showed an increase of 44.36%, which was the lowest. Along with reduction of particle size, additional blending also aids in incorporation of the loose cell wall material into the solution, thus improving WHC. The large cotyledonary tissue is broken down into smaller particles and a porous fibrous matrix is formed, which absorbs more moisture. Additional blending significantly affected the WHC values at equilibrium for all the samples. WHC increased with particle size reduction as a result of additional blending (AB).

Whipping (AW) showed a very minimal affect on water holding capacity. All of the plate mill samples showed a decrease in WHC as a result of this treatment. PM-270, PM-180 and PM-90 showed a decrease in WHC due to this treatment. HM-2.54 showed the greatest increase of 7.97% to 15.47 g/g. PM-90 showed the greatest decrease of -12.35% to 15.81 g/g. The increase in WHC in smaller particle sized samples can be attributed to the particle aggregation, thus aiding in increased water holding capacity. Irmouli and Haluk (2002) reported aggregation of particles in fine powders as a result of agitation and pumping. Overall, WTM showed the highest WHC after whipping (17.96 g/g) followed by PM-360 (16.57 g/g), PM-180 (16.32 g/g), PM-0 (16.31 g/g), HM-1.73 (16.17), PM-270 (16.06 g/g), PM-90 (15.81 g/g), WM (15.61 g/g) and HM-2.54 (15.47 g/g).

The WHC after whipping is significant because this is the last step before frying. This WHC finally translates into the end product quality. This step is very important for air incorporation into the paste to produce the desirable spongy texture

of *akara*. Absence of this step would lead to increased WHC for some samples.

Whipping time may be another factor that can be manipulated to optimize the amount of air incorporation and WHC.

**Table 2.7.** Water holding capacity (WHC) of freeze-dried cellular materials from different cowpea pastes.<sup>1</sup>

Sample	BB (g/g)	AB (g/g)	AW (g/g)	Percent Change	Percent Change
WTM	12.12a	17.50ab	17.96a	44.36	2.66
PM-360	4.32f	17.95a	16.57ab	315.51	-7.69
PM-270	4.74ef	17.31ab	16.06b	265.11	-7.20
PM-180	4.93de	18.05a	16.32ab	266.35	-9.60
PM-90	5.32de	18.04a	15.81b	238.83	-12.35
PM-0	6.21c	16.95ab	16.31ab	173.11	-3.79
HM-2.54	6.38c	14.33d	15.47b	124.67	7.97
HM-1.73	8.44b	16.00bc	16.17b	89.62	1.04
WM	5.35d	15.27cd	15.61b	185.37	2.24

<sup>1</sup> a, b, c, d, e, f: Mean values in a column not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); BB (before blending), AB (after blending), AW (after whipping); WTM (wet milled), PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill).

### *Swelling Capacity*

The observed values for swelling capacity (SWC) were in accordance with the reported observations by Kethireddipalli et al. (2002b). WTM had the highest SWC before blending (BB); HM-1.73 had lower SWC than WTM but was higher than all other samples, which were not significantly different (Table 2.8). After blending (AB), WTM had the highest value whereas HM-2.54 and WM had the lowest. After whipping (AW), WTM and PM-270 had the highest SWC and HM-2.54 the lowest.

It can be seen from Table 2.8 that the control (WTM) swelled the most (22.7 mL/g) before blending (BB). It was about double the other samples, except HM-1.73 (14.7 mL/g). This is in accordance with the WHC results where WTM showed maximum WHC followed by HM-1.73. HM-1.73 showed a high amount of swelling because of its fine particle size distribution and hence the presence of more fiber and increased surface area in the cellular material (Kethireddipalli et al., 2002b). WM had the least SWC of 10.0 mL/g followed by PM-180 and PM-90 which showed values of 10.7 mL/g each. PM-360 swelled to 11 mL/g of sample; PM-270 and PM-0 had a similar value of 11.3 mL/g.

Additional blending (AB) improved the SWC of all samples. WTM showed the highest SWC of 39.5 mL/g followed by PM-270 (34.5 mL/g), PM-360 (34.0 mL/g), HM-1.73 (34.0 mL/g), PM-180 (33.5 mL/g), PM-90 (33.0 mL/g), PM-0 (32.0 mL/g), HM-2.54 (28.5 mL/g) and WM (25.5 mL/g). WTM showed the least increase of 74.26%. This can be attributed to the fact that the cellular material derived from WTM BB already had a high amount of fiber. Therefore, blending resulted in a relatively small increase in SWC of this sample. The larger-sized plate mill samples

showed marked increases (214.06% to 204.41%) over the previous treatment. Owing to their larger particle size, plate mill samples had hardly any fiber from the cell wall material (CWM) before blending. After blending, the cotyledonary tissue is hydrated, particle size is decreased, and the fibrous material is released into the solution, thus leading to its higher content in the extracted cellular material and improved SWC.

The smaller-sized samples (HM-1.73, PM-0, HM-2.54 and WM) showed low particle size reduction (Table 2.5) after blending. These samples already had the fiber present in their cellular material. Due to this, they showed a lesser improvement in SWC as compared to larger-sized counterparts.

Whipping (AW) further improved SWC for all samples, except HM-1.73 (-3.92%). PM-360, PM-0, and WM showed significant improvement over AB. WTM showed an improvement of 3.80% to 41.0 mL/g. WM showed the highest increase (30.72%) and improved the SWC to 33.3 mL/g. PM-0 and HM-2.54 also had a positive increase of 13.54 and 11.11%, respectively. The larger-plate mill samples showed an increase ranging from 7.07% to 11.11%. The samples with intermediate mean particle sizes before blending (360-480 microns) showed an improved SWC after whipping (AW) whereas the sample with a low  $d_{gw}$  of 220 microns (HM-1.73) showed an actual reduction in SWC after whipping. The larger-sized samples (690-1560 microns) exhibited an intermediate improvement in SWC. Overall WTM had the highest SWC of 41.0 mL/g followed by PM-270 (38.3 mL/g), PM-360 (37.0 mL/g), PM-180 (36.7 mL/g), PM-0 (36.3 mL/g), PM-90 (35.3 mL/g), WM (33.3 mL/g), HM-1.73 (32.7 mL/g) and HM-2.54 (31.7 mL/g).

**Table 2.8.** Swelling capacity of freeze-dried cellular materials from different cowpea pastes <sup>1</sup>

Sample	BB (mL/g)	AB (mL/g)	AW (mL/g)	% Change (BB to AB)	% Change (AB to AW)
WTM	22.7a	39.5a	41.0a	74.26	3.80
PM-360	11.0c	34.0b	37.0bc	209.09	8.82
PM-270	11.3c	34.5b	38.3ab	204.41	11.11
PM-180	10.7c	33.5b	36.7bc	214.06	9.45
PM-90	10.7c	33.0b	35.3bcde	209.38	7.07
PM-0	11.3c	32.0b	36.3bcd	182.35	13.54
HM-2.54	10.7c	28.5c	31.7e	167.19	11.11
HM-1.73	14.7b	34.0b	32.7de	131.82	-3.92
WM	10.0c	25.5c	33.3cde	155.00	30.72

<sup>1</sup> a, b, c, d, e: Mean values in a column not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); BB (before blending), AB (after blending), AW (after whipping); WTM (wet milled), PM (Plate milled samples are followed by the number of degrees of clearance), HM (Hammer milled samples are followed by the size of screen in mm) and WM (Wiley mill).

### *Conclusions*

This study shows that milling affects the particle size distribution, which in turn is a major determinant of hydration properties of meals and flours. All milling techniques have a different mechanism by which particle size reduction is obtained. This basic principle leads to varying particle size distributions for a sample when milled through different mill screens and clearances. Material milled through a similar sized screen but by a different mill can lead to a totally different PSD. In our study, the Wiley mill used a 2.00 mm screen whereas HM-1.73 and HM-2.54 used a 1.73 mm and 2.54 mm screens, respectively. Normally it would be expected that the  $d_{gw}$  of WM should lie between the HM samples. However, this was not true. WM produced a much greater  $d_{gw}$  than HM samples.

Plate mill (PM) samples milled through larger clearances (PM-360, PM-270 and PM-180 degrees) produced higher SWC and WHC after blending. The higher hydration characteristics were attributed to the initial gritty size of particles. This aided in preservation of cellular structure and hence the fibrous material. The finer particle size samples such as HM-1.73, HM-2.54 and WM produced flours that had a lower SWC and WHC after whipping. Fine milling enhances protein solubility, but it adversely affects the hydration properties of paste. This also leads to lower viscosity and poor foaming properties. Due to the intensity of milling, the cellular structure and the fibers therein are destroyed. Smaller-particle size samples like HM-1.73 showed high values for SWC and WHC before blending (BB). This can be attributed to the fact that intense milling resulted in an increase in the total surface area and total pore volume of HM-1.73. This leads to an increased WHC and SWC for the sample.

This study also demonstrated the very important role of additional blending in improving hydration properties of all samples. Before the step of additional blending, the particle sizes were very widely distributed. Blending reduces the particle size considerably. In some cases it seems that particle coagulation is taking place. Previous studies (Kethireddipalli et al., 2002ab) had shown that the unblended meals and flours produced poor quality *akara* because of poor hydration properties. Blending improved WHC for all samples from 89.62 to 266.35%. SWC was also improved within a range of 131.82 to 214.06%.

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**SECTION III**  
**A SYSTEMATIC APPROACH TO ENHANCE THE QUALITY OF AKARA**  
**(FRIED COWPEA PASTE)\***

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### Abstract

Particle size distribution is an effective tool for product matching and development. Dry milled samples can be used to produce *akara* with quality comparable to the wet milled product. All blended samples showed a reduction in viscosity after whipping ranging from 48.24% to 54.19%. Specific gravity showed a similar trend. HM-1.73 (Hammer mill with 1.73 mm screen) produced the least number of *akara* balls per batch with highest per ball weight. *Akara* moisture content varied from 48.58% to 54.66%. *Akara* made from HM-1.73 had the least amount of fat (14.65%) as compared to the control and PM-360 (Plate mill with one turn (360°) clearance), with 33.05% and 32.26% fat, respectively. Ash and protein content of samples varied from 6.81% to 7.52% and 22.61% to 23.34%, respectively. *Akara* made from HM-2.54 (hammer mill with 2.54 mm screen) was acceptable to the largest number of respondents (91.25%). Wet milled (WTM) *akara* was rated the oiliest and HM-1.73 least oily.

Keywords: *Akara*, particle size distribution, milling, cowpea meal, functional properties, proximate analysis, sensory evaluation

## Introduction

Cowpeas (*Vigna unguiculata*) are a major source of dietary protein and B-vitamins in East and West Africa. Cowpea is very important in the African diet because it contains 20-30% protein, with complementary amino acids to cereals, 55-58% carbohydrates, 2-3% fat, and 2-3% minerals and vitamins (Enwere and Ngoddy, 1986).

Whipped cowpea paste is seasoned with fresh peppers (hot or mild), salt, and onions before it is fried in hot oil to make *akara*. Traditionally, *akara* is made by a tedious, time-consuming wet milling procedure (WTM). Several researchers have suggested rehydratable cowpea flour to simplify *akara* preparation (McWatters, 1983; Ngoddy et al., 1986). However the rehydratable flour was found to have many drawbacks. The *akara* produced was dry, tough, and dense in texture, which was not acceptable to consumers. This was attributed mainly to lack of foaming capacity and hydration properties of dry flour pastes (Kethireddipalli et al., 2002ab). These characteristics of paste functionality are influenced largely by the small particle size distribution of rehydratable flour (McWatters and Chhinnan, 1985; McWatters, 1983; Ngoddy et al., 1986). Grinding of cowpea not only reduces its particle size but also alters its fiber matrix structure. This lowers the water holding capacity and swelling capacity of dry hydrated meal (Cadden, 1987; Auffret et al., 1994).

Blending and whipping are important steps in processing of cowpea into *akara*. Blending clearly aids in reducing the particle size of paste to a more acceptable level and thus aiding in better distribution of moisture. Whipping incorporates air into paste, thus making it foam and giving it good dispensing properties and frying qualities (Mbofung et al., 2002).

The functional characteristics of paste determine the textural quality of *akara*. Foaming and hydration are the important functional characteristics of cowpea paste used in *akara* production (McWatters et al., 1988). Particle size distribution (PSD) in the solution also has an influence on paste functionality (Cadden, 1987). In a previous study (Singh, 2003) it was noted that the type of milling technique used had an influence on the particle size distribution and hydration properties of cellular material. Singh (2003) found the plate mill sample to have closest PSD to the WTM. The purpose of this study was to use particle distribution as a tool to enhance the quality of *akara* made from dry meal.

## **Materials and Methods**

### *Cowpea flour production*

Cowpea seeds (California Cream variety) were obtained from Inland Empire Foods, Riverside, Calif. A small amount of seed (2g) was ground and its moisture content determined in a vacuum oven (18 h, 70 °C and 25 mm Hg). The moisture content was found to be 10.12%. Uncorticated cowpea seeds were milled using two different mills, namely, plate mill (PM) and hammer mill (HM). Wet milling was used as the control. Screen sizes of 1.73 mm (HM-1.73) and 2.54 mm (HM-2.54) were used with the hammer mill (Champion, Model no. 6X14, Champion Products Inc., Eden Prairie, Minn.). The mechanics of hammer milling have been very well described by Ajayi and Clarke (1997). The clearance was varied on the plate mill by turning a screw in (for decreased clearance) or out (for increased clearance), thus affecting the distance between the two plates. The screw was turned all the way in and slowly unscrewed to calibrate before a milling run. The screw was marked and the angle of each turn measured and controlled. One full turn was designated to be 360°. The seed was milled at a clearance of 0 turn (PM-0) and 1

turn (PM-360) (Table 3.1). The seeds and milled material were stored in sealed containers at 7 °C until used.

**Table 3.1.** Plate milling protocol

Sample	First Pass (Degrees out)	Second Pass (Degrees out)	Third Pass (Degrees out)	Fourth Pass (Degrees out)
PM-360	720	720	540	360
PM-0	540	360	180	0

#### *Preparing the pastes*

The pastes were prepared by adding a pre-determined amount of moisture to the meals/flours. Wet mill (WTM) and PM-360 were prepared at 64% paste moisture content. PM-0 and HM-2.54 were adjusted to 61% moisture content and HM-1.73 to 58% moisture. The selection of moisture content was based on the viscosity of whipped paste at various moisture contents with the WTM at 64% moisture content (Patterson et al., 2002) as the benchmark.

#### *Paste preparation for particle size distribution*

The WTM paste was prepared by the method developed by Patterson et al. (2002). Seeds were soaked for 3 hrs, chopped in a food chopper (Sunbeam Oskar, model no. 14081, Sunbeam Appliance Co., Oakbrook, Ill.) for 1.5 minutes (stopping every 30 seconds to scrape the sides), blended at high speed (Osterizer 12-speed blender, Sunbeam Corp., Milwaukee, Wis.) with the appropriate amount of water for a pre-determined length of time (2.5, 3.5, 4.5 and 5 minutes) and whipped at speed 3 (high) (Hobart mixer, model N50, Hobart Corp., Troy, Ohio) for another 1.5 minutes.

For preparation of dry cowpea meal/flour, two plate-milled samples (PM-360 and PM-0) were selected for this study. PM-360 was selected for its proximity in mean particle size to the control (Singh, 2003) and PM-0 was selected to demonstrate the effect of smaller particle size but from the same milling method on *akara* quality. PM-360 and PM-0 were soaked with a pre-determined amount of water for 15 minutes (Kethireddipalli et al., 2002a) each (before blending-BB), blended for 5 minutes (after blending-AB) and then whipped for 1.5 minutes (after whipping-AW). The same appliances used for blending and whipping the wet-milled control paste were also used for pastes made from rehydrated meal/flour. Each treatment (BB, AB, AW) was tested for particle size distribution.

#### *Paste preparation for akara*

WTM was prepared by the method similar to that described above. In addition to the two plate mill samples, two hammer mill samples (HM-1.73 and HM-2.54) were also selected for this study because hammer mill is a commonly used mill and had been effectively used for meal preparation for *akara* in various studies (McWatters et al., 1988; Mbofung et al., 2002). PM-360, PM-0, HM-1.73 and HM-2.54 were all soaked with a pre-determined amount of water for 15 minutes and then blended for 4.5, 3.5, 0, and 5 minutes, respectively, before whipping for 1.5 minutes. The blending times for PM-360 and PM-0 were determined from the particle size analysis of these samples at various blending times. The blending time that produced the closest match to WTM particle size was selected. HM-1.73 was not blended to demonstrate the affect of lack of additional blending on the functional properties of paste and *akara* quality when compared to other blended samples. HM-2.54 was blended for 5 minutes to simulate the

blending time used for WTM (Patterson et al., 2002). The same appliances used in preparation of pastes for particle size distribution were used.

#### *Particle size distribution*

Wet particle size distribution was determined by laser diffraction using a Mastersizer S (Malvern Instruments, Worcestershire, UK). This instrument requires particulate samples to be completely disassociated and suspended in a liquid. The measurement principle is based on simultaneous multi-angle detection of scattered light. Samples are passed through a He/Ne laser, and the Malvern Mastersizer then calculates a size distribution from the raw light energy data using a statistical package (Rawle, 2001). The Mastersizer S detector array acquires light scattering data at the rate of 500 Hz (one measurement every 2 milliseconds) and the amount of light scattered is inversely proportional to the particle size of the material.

The refractive indices of the liquid and the sample are needed for the analysis. The presentation code is also needed for the calculation and was selected based on the particle refractive index. However, this information was not available for cowpea meal. The “wet standard presentation” was selected to represent the optical model of light scattering and used for calculating the particle size distribution of pastes. For measurement purposes, 1 g of sample was diluted in 100 mL deionized water. A disposable pipette was then used to introduce sample into a small volume presentation unit of the instrument, which already contained ~120 mL of deionized water, until the unit showed 13% obscuration level. Obscuration, the fraction of light lost from the main beam when the sample is introduced, serves as an indication of overall particle concentration (Moughal et al., 2000). The unit pumped the sample through the optical

cell by a stirrer that rotated at ~ 2100 rpm. The Malvern optical model calculates the relative volume distribution of particles and other size distribution parameters from the light scattering data assuming an equivalent sphere. Size distributions (volume fractions against particle size) were calculated.

ASAE Standard S319 (ASAE Standards, 1994) was used for calculating the geometric mean diameter ( $d_{gw}$ ) and geometric standard deviation of sample estimate ( $S_{gw}$ ). The following formulas were used to calculate  $d_{gw}$  and  $S_{gw}$ .

$$d_i = (d_i \cdot d_{i+1})^{1/2}$$

$$d_{gw} = \log^{-1} [\Sigma (W_i \log \bar{d}_i) / \Sigma W_i]$$

$$S_{gw} = \log^{-1} [\Sigma W_i (\log \bar{d}_i - \log d_{gw})^2 / \Sigma W_i]^{1/2}$$

Where

$d_i$  = diameter of sieve openings of the i'th sieve

$d_{i+1}$  = diameter of openings in next larger than i'th sieve (just above in a set)

$d_{gw}$  = geometric mean diameter

$\bar{d}_i$  = geometric mean diameter of particles on i'th sieve

$S_{gw}$  = geometric standard deviation

$W_i$  = weight fraction on the i'th sieve

#### *Viscosity measurements*

Viscosity of pastes after blending (AB) and after whipping (AW) was measured at 23 °C with a Brookfield viscometer (HATD model, Stoughton, Mass.) equipped with a Model C Helipath stand and TC spindle operated at 10 rpm. The batter was scooped into a 250 mL beaker and tapped 10 times on the heel of the palm to remove any air pockets. The viscometer was leveled using the inbuilt leveler; each reading was taken after the

spindle was immersed in batter and after 10 rotations. The viscosity readings for all samples were taken in triplicate.

#### *Specific gravity*

Specific gravity was determined by the method described by Campbell et al. (1979). A U.S. standard dry measuring  $\frac{1}{4}$ <sup>th</sup> cup size (~ 60 mL) was used for the measurements. The volume of the cup was determined by using tap water. For specific gravity measurement, the cup was filled to the brim with paste and then gently tapped (~ 10 times) to remove any large air bubbles. The excess paste was scraped off using a flat edged knife. The following formula was used to calculate specific gravity of the samples:

$$\text{Specific gravity} = \frac{\text{Wt. of plastic filled cup} - \text{wt. of empty cup}}{\text{Wt. of water filled cup} - \text{wt. of empty cup}}$$

The readings in triplicate were taken after blending (AB) and after whipping (AW).

#### *Conditioning (break in) the oil*

For uniform results in frying, the cooking oil was conditioned (broken in) before the actual frying (Chinnan, 2003). A day before frying samples for analytical and sensory evaluation, 20 batches of *akara* were fried in 1 liter of fresh oil to simulate the actual frying conditions. The twenty batches were selected to represent 4 batches each of 5 different pastes. Each batch had about eight balls and each ball weighed 15-18 g. The amount of fat in each ball was approximately 30%, most of which was taken up from the frying oil. Therefore, each ball took up about 5 g of fat on an average. Oil uptake after

each batch, was about 40 g. The oil absorbed by each batch was replenished after each batch of frying. When the temperature reached 193 °C, the next batch was fried. The oil loss was calculated from the oil content calculated in preliminary studies.

Oil was filtered after each day of frying to prevent crumbs from degrading the oil. Crumbs have been reported to contribute to dark oil color, high fatty acid content, scorched or burnt flavor, and short fry life of oil (Banks, 1996).

#### *Preparing akara*

*Akara* was fried by the method described by Patterson et al. (2002). *Akara* was prepared from PM-0, PM-360, HM-1.73, HM-2.54 meal/flour and the control (WTM). The batter was dispensed with a # 40 (~ 20 mL) ice cream scoop into a 6-quart bench-top fryer (Presto, National Presto Ind. Inc., Eau Claire, Wis.) containing 1 liter of peanut oil, preheated at 193 °C for 2 min with turning after 1 min to prevent uneven cooking. The temperature was controlled by a digital thermometer equipped with a type-K thermocouple probe. The batter was dropped in the oil as the temperature was rising. After frying, samples were removed from the fryer and drained on paper towels for 15 minutes before placing them in freezer bags and storing in a refrigerator. The fried samples for proximate composition analysis were evaluated immediately after being cooled for 15 min. The samples to be evaluated for acceptability by an untrained consumer panel were cooked one day before the consumer panel.

#### *Physical characteristics and proximate analysis*

The number of *akara* balls made from 100 g of starting material were counted; a representative number was weighed, and the mean weight of balls expressed in grams. Moisture content of all samples was determined from the difference in weight before and

after vacuum drying a ground and pre-weighed amount of samples for 24 h at 70° C [American Association of Cereal Chemists (AACC), 1976; Method 44-40]. Moisture-free sample was used to determine crude fat by extraction with petroleum ether for 24 h in a Goldfish apparatus (Labconco, Kansas City, Mo.) (AACC, 1976, Method 30-26). The fat-free, moisture-free sample was used to determine protein content by a nitrogen combustion method (LECO, FP-2000, Warrendale, Penn.). The nitrogen content was multiplied by a factor of 6.25 to determine the protein content [Food and Agricultural Organization of the United Nations (FAO), 1970]. Moisture-free and fat-free sample was also used for ash determination using AACC method 08-01 (AACC, 1976). Carbohydrate content was determined by subtracting oil, protein and ash content from 100 %. Measurements were made on all samples in triplicate.

#### *Color measurements*

Instrumental color measurements of the exterior surface of five *akara* balls per batch were obtained with a Minolta Chroma Meter (Model CR-200, Osaka, Japan). Readings were taken at three points on the surface of three *akara* balls per batch. After calibration and standardization with a brown reference tile ( $L^* = 69.82$ ,  $a^* = 19.17$ ,  $b^* = 31.75$ ), the  $L^*$ ,  $a^*$ ,  $b^*$  values were recorded. Other derived attributes [chroma (C), hue angle ( $H^\circ$ ) and total color difference ( $\Delta E$ )] were determined according to the formulations described in Hung (1990). All measurements were made in triplicate.

#### *Measurement of akara texture*

Texture profile analysis (TPA) was used to evaluate the objective textural quality of *akara*. The procedure developed by Friedman et al. (1963) and modified by Kethireddipalli et al. (2002a) was used. Approximately 1 cm<sup>3</sup> portion from the crumb of

*akara* was cut. The cube was compressed twice in a reciprocating motion to 25% of its original height. Compression was done in an Instron universal testing machine (Model 5544; Instron Inc., Canton, Mass., U.S.A.) fitted with a 2000 N load cell. The cube was compressed to 2.5 mm at a crosshead speed of 50 mm/min; the crosshead returned at 1000mm/min and the cube was recompressed back to 2.5 mm under the same conditions. The TPA parameters, namely, hardness, cohesiveness, springiness, and chewiness were derived from force deformation curves (Friedman et al., 1963; Hung et al., 1988). Triplicate measurements for each batch were made.

#### *Sensory evaluation*

An untrained consumer panel of 40 people was used to determine *akara* acceptability. Panelists were recruited from the faculty, staff, and students of the Department of Food Science and Technology. All panelists were regular consumers of fried foods and had no allergies to cowpeas or peanut oil.

A standard nine-point hedonic scale (1 = dislike extremely, 9 = like extremely) was used to evaluate the appearance, color, aroma, flavor, texture, oiliness, and overall liking of the five samples. Since high oil content is perceived by consumers to be negative, a higher hedonic value for oiliness meant that the sample had less oil and thus was liked better. Panelists also filled out a consent form and a fried foods questionnaire with some demographic questions.

All consumers were served the same reheated sample at the same time. The reheating schedule was randomized for statistical integrity. The samples were served warm by the method developed by Patterson (2002). All samples were heated from the refrigerated state for 6 minutes in a conventional oven preheated to 204 °C. They were

allowed to cool for one minute before being served in 2 oz plastic soufflé cups. There was a five-minute break after serving the first three samples for panelists to complete the questionnaires and to prevent sensory fatigue. All panelists were encouraged to expectorate the sample, eat unsalted saltine crackers, and rinse their mouths with lemon water (18 mL lemon juice in 1 liter water) to clean their palates before tasting the next sample. Two processing replications with the same panelists were carried out.

#### *Statistical analysis*

Analysis of variance (ANOVA) procedures were used to analyze the data (SAS, 2002). Mean separation was performed by the LSD test ( $\alpha = 0.05$ ).

### **Results and Discussion**

#### *Particle size distribution*

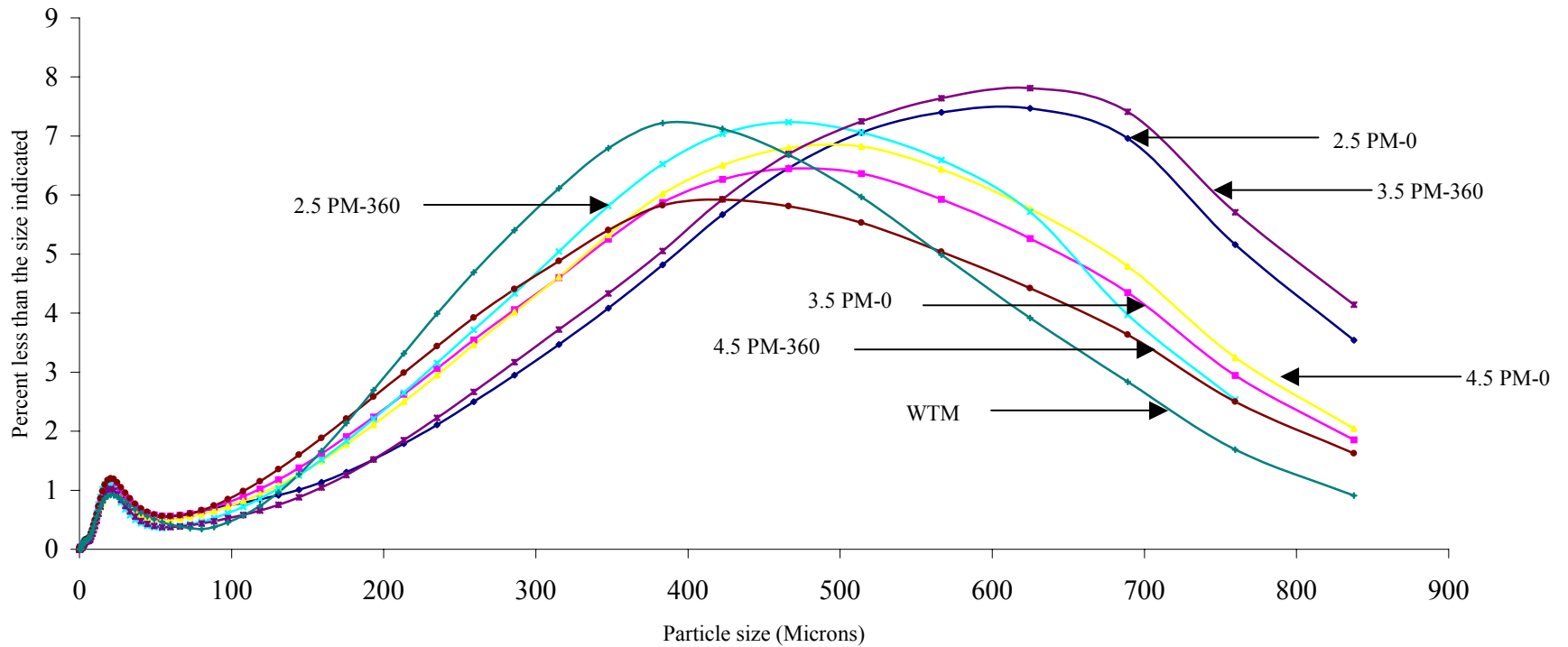
In a previous study, Singh (2003) reported that the particle size distribution (PSD) of plate-milled samples was the closest to that of the control (WTM). Two hammer mill samples (HM-1.73 and HM-2.54) were included in the study because we were interested in the *akara* produced from finer particle sized meals and their acceptance by the consumers. We also wanted more samples in the study so that the respondents could have a range of products to compare.

The AW (after whipping) curves (for all samples with different treatments) are shown in Figure 3.1. The particle size data from differently blended samples was subjected to homogeneity slope and intercept tests (SAS, 2002) to determine if the curves were a close match to the control (WTM). The tests were performed on linear models of the data recorded. It was observed from the homogeneity and slope intercept tests that PM-360 blended for 4.5 minutes was the only sample that had no significant difference

from the WTM (control), thus leading to its selection for further study. To select a PM-0 sample we had to rely on  $d_{gw}$  data (Table 3.2). There was no certain trend in particle sizes recorded. The particle size closest to that of WTM from AW was selected for PM-0 after whipping. It is evident that PM-0 blended for 3.5 minutes had the best match with the control (WTM blended for 5 minutes). The particle size distribution curves for selected blending times of cowpea pastes from wet and dry milled samples are depicted in Figure 3.2.

Critical parameters describing all curves are shown in Table 3.3, and include total volume percent of particles under given peaks (peak 1 and peak 2), particle size at maximum volume percent ( $dm_1$  and  $dm_2$ ) and size at which peak 1 ends (ends at). By following the changes in mode of peak 1 and peak 2 ( $dm_1$  and  $dm_2$ ), % volume of particles under peak 1 and peak 2, we can monitor the shift in particle concentration after each treatment (BB, AB and AW).

The mode of peak 1 ( $dm_1$ ) was the same for all of the treatments. There was no particular trend noted in the critical parameter values. The values from WTM reaffirm the conclusion that blending (AB) reduces the particle size substantially whereas whipping (AW) has a minor effect. For approximately the same volume of particles under peak 1 (~18%) and peak 2 (~82%),  $dm_2$  decreased significantly after blending (689 to 422 microns). PM-360 blended for 4.5 min had a  $dm_2$  of 422 microns (AW), which was the closest match to WTM (AW of  $dm_2$  at 383 microns) while they held 89 and 82% particles under peak 2, respectively. PM-0 blended for 3.5 minutes was the closest match to WTM AW with a  $dm_2$  of 466 microns and holding 90% particles under peak 2.



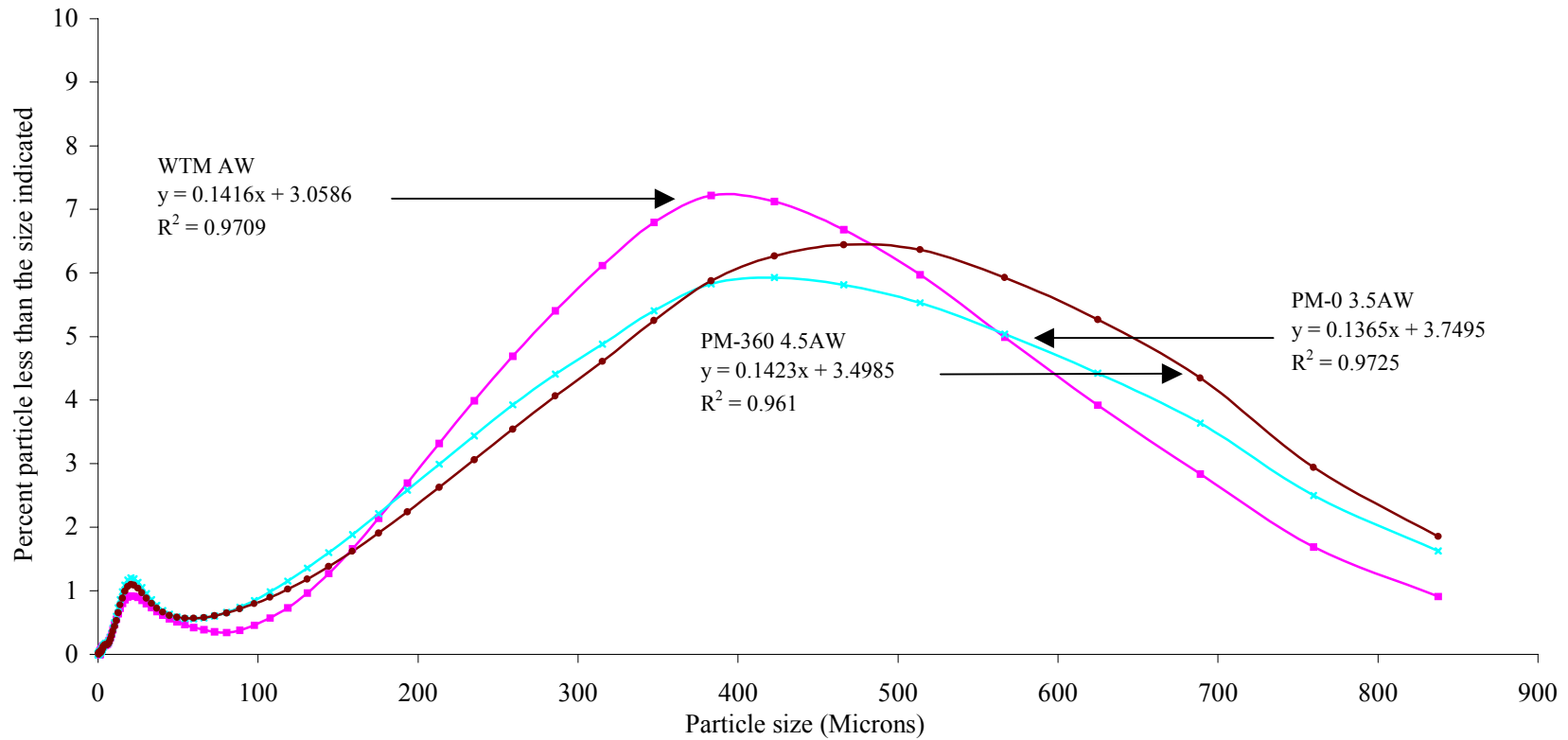
**Figure 3.1.** Particle size distribution plots for various (2.5, 3.5, 4.5 min.) blending times of cowpea pastes from wet and dry milling treatments; WTM = wet milled; PM-0 = plate mill 0° clearance; PM-360 = plate mill 360° clearance.

**Table 3.2.** Geometric mean diameter ( $d_{gw}$ ) values for differently blended cowpea pastes from selected wet and dry milling treatments <sup>1</sup>

Sample	2.5 AB	2.5 AW	3.5 AB	3.5 AW	4.5 AB	4.5 AW	BB	AB	AW
PM-360	214.2bc (3.9)	222.0b (3.9)	218.0bc (3.6)	242.7a (3.7)	204.20c (3.7)	179.3d (3.6)	...	...	...
PM-0	234.6a (3.9)	219.2a (3.9)	206.3a (3.6)	196.3a (3.7)	213.5a (3.7)	212.7a (3.6)	...	...	...
WTM <sup>2</sup>	...	...	...	...	...	...	268.7a (2.6)	210.1b (2.1)	199.5b (1.9)

<sup>1</sup> a, b, c, d: Mean values in a row not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); WTM (wet mill) and PM (plate milled samples at mentioned clearance in degrees); BB (before blending), AB (after blending), and AW (after whipping); Geometric standard deviation of sample estimate ( $S_{gw}$ ) values are italicized and placed in parentheses below the corresponding  $d_{gw}$  values

<sup>2</sup> The sample was blended for 5 minutes.



**Figure 3.2.** Particle size distribution plots for selected blending times (PM-0 3.5 min and PM-360 4.5 min) of cowpea pastes from wet and dry milling treatments; WTM = wet milled; PM-0 = plate mill 0° clearance; PM-360 = plate mill 360° clearance; AW = after whipping.

**Table 3.3.** Peak volume and modal data of cowpea and flour mill pastes from selected wet and dry milling treatments <sup>1</sup>

Parameter	WTM			PM-360						PM-0					
	BB	AB	AW	2.5 AB	2.5 AW	3.5 AB	3.5 AW	4.5 AB	4.5 AW	2.5 AB	2.5 AW	3.5 AB	3.5 AW	4.5 AB	4.5 AW
Peak 1	18.38	17.12	17.50	10.07	9.28	10.27	8.74	9.65	10.47	9.52	9.54	9.40	9.48	8.94	8.63
dm <sub>1</sub>	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42
Ends at	65.98	72.76	80.23	59.84	59.84	59.84	59.84	59.84	59.84	54.27	54.27	59.84	59.84	59.84	59.84
dm <sub>2</sub>	689.01	422.651	383.29	513.90	513.90	566.66	624.85	513.90	422.65	624.85	624.85	466.04	466.04	513.90	513.90
Peak 2	81.62	82.88	82.50	89.93	90.72	89.72	91.25	90.34	89.52	90.47	90.45	90.59	90.51	91.05	91.36

<sup>1</sup> WTM (wet mill), and PM (plate milled samples at mentioned clearance in degrees); BB (before blending), AB (after blending), and AW (after whipping); peak 1 and peak 2: volume of particles under corresponding peaks; dm<sub>1</sub> and dm<sub>2</sub>: modal points for peak 1 and peak 2

### *Specific gravity and viscosity of pastes*

Viscosity and specific gravity are important factors in *akara* quality as they determine paste functionality (McWatters et al., 1988). Hanselmann and Windhab (1999) reported that foam viscosity determines the structure and stability of a foam. The reduction in paste specific gravity after whipping (AW) is a direct measure of its foaming capacity (Campbell et al., 1979).

The calculated values for viscosity and specific gravity are shown in Table 3.4. The viscosity values were significantly different for all samples after blending (AB). HM-1.73 had the highest viscosity (146291 cp) because it was not blended. Blending leads to a reduction in particle size of the sample, and this increases the total surface area for moisture absorption. In an unblended sample, the surface area available is less and so the moisture absorption is not optimum, thus producing a highly viscous paste. Kethireddipalli et al. (2002a) reported low viscosity for unblended fine flour paste, but the paste was prepared at very high moisture content and there was a lot of free water in it. The *akara* prepared from that paste was reported to have very poor frying properties. The control showed a viscosity of 94155 cp before whipping. PM-0 had a viscosity of 84183 cp before whipping and was closest to the control. After whipping, PM-360 and WTM showed a reduction in viscosity of 54.19 and 53.48%, respectively. Whipping had the least affect on HM-1.73, which showed a viscosity reduction of only 39.82%. Kethireddipalli et al. (2002a) reported a reduction in the foam volume of whipped flour paste as the flour particle size became finer. This reduction in volume leads to increased viscosity and specific gravity of paste. WTM and PM-0 were not significantly different in viscosity after whipping. Other samples showed differences in viscosity values. It is

apparent that samples with smaller particle size show lower reduction in viscosity after whipping. If foaming ability of a protein is low, the foam is not very stable (Kinsella, 1976).

Specific gravity also showed a similar trend as viscosity. HM-1.73 had the highest specific gravity after whipping (0.94) and showed the least reduction in specific gravity after whipping (13.97%). Lack of particle size reduction in HM-1.73 leads to less total surface area and hence lowers incorporation of air. PM-360 had the lowest specific gravity (0.65) followed by the control (0.68). PM-360 also showed the highest reduction (36.72%) in specific gravity after whipping. Intense milling could have contributed to the low protein solubility of HM-1.73. At similar moisture content of 65%, the viscosity profile of samples was totally different (Kethireddipalli et al., 2002b). By negating the affect of difference in moisture contents, these researchers found that higher coarse cell wall material in the sample led to higher viscosity. They noted that unblended fine flour had very low viscosity at the same moisture content as wet-milled and blended meal paste. However, in a previous study they also found that fine flour with a very low viscosity was very difficult to dispense into oil and produced undesirable *akara* balls (Kethireddipalli et al., 2002a).

Protein solubility plays an important role in foamability and stability of the foam on whipping. A high reduction in specific gravity is an indicator of good foaming power and foam stability (Kinsella, 1976). This in turn is attributed to high protein solubility as a result of greater tissue disruption and release of solubles and macromolecules from the cells (Kethireddipalli et al., 2002b). The microstructure studies conducted by Kethireddipalli et al. (2002a) indicated that cellular material from blended meal paste and

fine flour paste had a large amount of intact cells (as compared to wet milled paste) and hence lower soluble solids in the solution. This led to lower protein solubility and hence higher specific gravity as compared to the control. In contrast, Kerr et al. (2000) reported that protein solubility increased with increasing fineness of flour.

**Table 3.4.** Effect of milling method, blending and whipping on viscosity and specific gravity of cowpea pastes <sup>1</sup>

Sample	Moisture (Percent)	Viscosity (cP)			Specific Gravity		
		AB	AW	% Reduction	AB	AW	% Reduction
WTM	64	94155b	43800b	53.48	1.01c	0.68bc	32.63
PM-360	64	60133e	27550c	54.19	1.02bc	0.65c	36.72
PM-0	61	84183c	43575b	48.24	1.028bc	0.69bc	33.34
HM-2.54	61	70383d	35666bc	49.33	1.032b	0.70b	32.53
HM-1.73	58	146291a	88033a	39.82	1.09a	0.94a	13.97

<sup>1</sup> a, b, c, d: Mean values in a column not followed by the same letter were significantly different ( $\alpha = 0.05$ ); WTM (wet mill), PM (plate milled samples at mentioned clearance in degrees) and HM (hammer milled samples at mentioned screen size in mm); AB (after blending), and AW (after whipping).

*Physical and proximate characteristics of akara*

Physical and proximate characteristics of *akara* prepared by different milling methods are shown in Table 3.5. PM-360 and WTM made the most number of balls (15) from 100 g of starting material. HM-1.73 made only 11 balls from the same amount of starting material. It is apparent that the number of balls made is directly related to specific gravity and amount of moisture added to the samples. The lower moisture content (58%) and higher specific gravity after whipping (0.94) of HM-1.73 resulted in fewer balls than the control (WTM) and PM-360 which had low specific gravity after whipping (0.68 to 0.65) and higher moisture content (64%). The incorporation of air into the paste increased paste volume which produced more balls for the same amount of meal/flour. HM-2.54 and PM-0 had similar specific gravity (0.69 to 0.70) and moisture content (61%) and both produced 13 balls each.

HM-1.73 produced the heaviest balls (20.93 g) among all samples, whereas the control produced the lightest-weight balls (16.55 g). The average weight of an *akara* ball seems to be related to the specific gravity of the paste after whipping. Lower specific gravity means high amount of air incorporation and hence spongier balls having lower weight than less spongy balls. Specific gravity after whipping and average ball weight show a high correlation ( $r = 0.92$ ).

*Akara* from HM-1.73 had 51.87% moisture. This seemingly high amount can be attributed to the fact that flour with small particle size tends to form a thick crust very early in the frying process and hence impedes the transfer of heat to inner portions of the *akara* ball (McWatters, 1983). This retains the moisture in *akara* produced from small particle-sized flours. McWatters and Chhinnan (1985) also reported similar findings for

a finely-milled meal used for paste preparation at 58% moisture levels. *Akara* from WTM showed a significantly lower amount of moisture (48.58%). This can mainly be attributed to its thin crust and hence higher exchange of moisture for fat during frying.

*Akara* from PM-360 and the control (WTM) contained 32.26% and 33.05% fat, respectively. There was no significant difference between these two samples. Specific gravity of paste samples after whipping and fat content of *akara* had a high negative correlation ( $r = -0.80$ ). A sample with higher specific gravity would be expected to produce a heavier and denser product. This in turn may also be responsible for lower fat uptake by the product. *Akara* made from HM-1.73 had the lowest amount of fat (14.65%) owing to the early formation of crust during frying and hence less oil uptake by the balls. Porosity of a sample (volume fraction of air or void fraction in sample) is inversely proportional to its particle density (Pinthus et al., 1995b). A paste with high air incorporation during whipping is increasingly porous and hence absorbs a high amount of oil. The increased oil uptake with porosity is most distinct in the beginning of frying (Pinthus et al., 1995a). HM-1.73 has high particle density owing to the absence of additional blending. High particle density translates into decreased porosity and hence less uptake of oil in the early stage of frying. A considerable amount of oil uptake in potato products occurs during the initial frying period (Keller et al., 1986). Due to reduction in porosity of the sample, crust formation is quick and hence less uptake of oil. The amount of oil uptake is also directly proportional to the amount of moisture lost from the sample (Rice and Gamble, 1989). McWatters and Chhinnan (1985) observed that fat content increased with an increase in paste moisture. Most of the oil held in a fried product is in the crust of the sample, and the oil layer is ~1 mm thick (Keller et al., 1986).

Our preliminary trials confirmed this trend. PM-360 and WTM had a high amount of initial moisture (64%) and hence took up a high amount of fat during frying. *Akara* from HM-2.54 and PM-0 had no significant difference in fat content (~21.00%). The lower fat content of these two samples can be attributed to a comparatively low amount of moisture content (61%) in their pastes.

*Akara* from PM-360 showed a significant difference in ash content (7.52%) from all other samples. HM-1.73 had the least amount of ash at 6.81%. This can be attributed to the lower amount of salt (1.5 % of paste weight) added to the paste. There was no significant difference in ash content for WTM, PM-0, HM-2.54, and HM-1.73. *Akara* from WTM had the highest amount of protein at 23.34% and was significantly different from HM 2.54 (22.61%), which had the lowest amount.

The carbohydrate content of *akara* from WTM and PM-360 was significantly different from HM-1.73, HM-2.54 and PM-0. Owing to HM-1.73 having the lowest fat content, by difference it had the highest amount of carbohydrates at 55.40%.

**Table 3.5.** Effect of milling method on proximate composition of *akara* <sup>1</sup>

Sample	<i>Akara</i> balls/ 100g flour	Wt. of ball (g)	Moisture (%)	Fat (%)	Ash (%)	Protein (%)	Carbohydrates (%)
WTM	15a	16.55b	48.58c	33.05a	7.10b	23.34a	36.50b
PM-360	15a	17.59b	51.51b	32.26a	7.52a	23.00ab	37.22b
PM-0	13b	17.27b	54.66a	21.10b	7.02b	22.74ab	49.14a
HM-2.54	13b	18.19b	53.66ab	21.06b	7.06b	22.61b	48.89a
HM-1.73	11c	20.93a	51.87b	14.65c	6.81b	23.14ab	55.40a

<sup>1</sup> Composition is expressed on dry weight basis; carbohydrate content was determined by difference; a, b, c, d: Mean values in a column not followed by the same lower case letter were significantly different ( $\alpha = 0.05$ ); WTM (wet mill), PM (plate milled samples at mentioned clearance in degrees) and HM (hammer milled samples at mentioned screen size in mm).

### *Texture profile analysis*

Texture parameters of *akara* from different milling methods are shown in Table 3.6. Considerable force (13.64 N) was required to press 1 cm<sup>3</sup> of *akara* from HM-1.73, thus making it the hardest sample. The control and PM-360 *akara* showed no significant difference in their hardness (6.44 and 6.80 N, respectively). Visually, HM-1.73 was noted to have a brittle crumb structure. Szczesniak (1963) observed that products noted for their brittleness always had high hardness values. PM-0 and HM-2.54 showed intermediate hardness values (9.22 and 7.51 N, respectively). Kethireddipalli et al. (2002a) reported that *akara* made from fine flour had hard texture as compared to *akara* prepared from the traditional wet milling procedure or from flour with coarse particles. Their reported hardness values were higher than in current study, but that could be attributed to their usage of decorticated seeds and a different cultivar of cowpeas. They also qualified the affect of paste blending and showed that additional blending reduced the hardness of *akara*. This was noted in the current study also. Various researchers (McWatters, 1983; Ngoddy et al., 1986) have reported a dry, dense, tough texture of *akara* prepared from fine flours. This undesirable trait is mainly attributed to intense grinding and the subsequent destruction of cell wall material (Kethireddipalli et al., 2002a). The control paste also produced *akara* with a desirable springy texture (2.28 mm). *Akara* produced from HM-1.73 was less springy (1.42 mm) than *akara* from other milling treatments and slightly more chewy (6.62 N.mm). Springiness is directly related to the spongy nature of the material being tested (Szczesniak, 1963). Higher springiness means that the food is spongier. Kethireddipalli et al. (2002a) observed that slightly higher values of cohesiveness and springiness coupled with a low hardness value gave

the much-desired spongy texture to traditional *akara*. Similar observations were made in this study also. There was no significant difference in cohesiveness and chewiness of *akara* from the different milling treatments. Szczesniak et al. (1963) developed standard rating scales for various mechanical properties and reported a high degree of correlation between mechanical and sensory observations.

**Table 3.6.** Effect of milling method on the texture profile of *akara* <sup>1</sup>

Sample	Springiness (mm)	Hardness (N)	Cohesiveness	Chewiness (N.mm)
WTM	2.28a	6.44c	0.45a	6.05a
PM-360	2.00ab	6.80c	0.44a	6.40a
PM-0	2.02ab	9.22b	0.29a	5.28a
HM-2.54	1.62bc	7.51bc	0.46a	5.97a
HM-1.73	1.42c	13.64a	0.38a	6.62a

<sup>1</sup> a, b, c: Values in columns not followed by the same letter are significantly different ( $\alpha = 0.05$ ); WTM (wet mill), PM (plate milled samples at mentioned clearance in degrees) and HM (hammer milled samples at mentioned screen size in mm); Springiness = height to which the sample recovers after first bite; Hardness = force required to deform the sample on first bite; Cohesiveness = area 2/ area 1 of the TPA curve and Chewiness = hardness \* springiness.

### *Instrumental color*

*Akara* made from HM-1.73 was the darkest sample with a lightness value of 49.78 (Table 3.7). This can be attributed to crust formation in the sample. The heat did not penetrate into the sample during frying and hence led to a darker surface. PM-0 and HM-2.54 produced the lightest-colored *akara* ( $L^*$  value of 56.97 and 55.81, respectively). *Akara* from HM-1.73 had the highest redness ( $a^*$ ) value of 16.88. There was no significant difference in redness among the other samples. HM-1.73 also produced *akara* with the lowest yellowness ( $b^*$ ) value (33.37).

Hue angles between  $40^\circ$  and  $75^\circ$  represent brown colors with a lower hue angle indicating more brown color than a higher angle (McWatters et al., 2001). The darker color of HM-1.73 can be explained by its lower hue angle ( $63^\circ$ ). There was no significant difference in hue angles of other samples, and they ranged from  $67.65^\circ$  to  $69.22^\circ$ . The samples from the current study using non-decorticated, cream-colored seeds were darker in color as compared to *akara* produced from decorticated blackeyes (McWatters et al., 2001). Patterson et al. (2002) also reported a lower hue angle for *akara* from wet-milled paste made from non-decorticated cream seeds. The present study further confirms the observation that non-decorticated seeds produce darker *akara*. This is probably due to the presence of cell wall material and pigments (McWatters et al., 1993). HM-2.54 had the highest value for chroma (39.79) and hence the most intense, saturated color.

Total color difference ( $\Delta E$ ) represents total color change due to treatment (McWatters et al., 2001). *Akara* from HM-1.73 was the most different in color (20.63). There was no significant difference in  $\Delta E$  between HM-2.54 and PM-0, which had the lowest values.

**Table 3.7.** Instrumental color measurements of *akara* from different milling methods <sup>1</sup>

Sample	L*	a*	b*	Hue angle (H°)	Chroma (C)	Δ E
WTM	52.75b	14.46b	35.11b	67.65a	38.06b	18.61ab
PM-360	54.71ab	14.75b	35.18b	67.30a	38.26b	16.84bc
PM-0	56.97a	13.70b	35.88ab	69.22a	38.47b	15.21c
HM-2.54	55.81a	14.96b	36.81a	67.88a	39.79a	15.94c
HM-1.73	49.78c	16.88a	33.37c	63.00b	37.49b	20.63a

<sup>1</sup> a, b, c: Values in columns not followed by the same letter are significantly different ( $\alpha = 0.05$ ); WTM (wet mill), PM (plate milled samples at mentioned clearance in degrees) and HM (hammer milled samples at mentioned screen size in mm); L\* = lightness (0 = black, 100 = white). Color measures of chroma  $(a^{*2} + b^{*2})^{1/2}$  and hue angle  $[\tan^{-1}(b^*/a^*)]$  were calculated from + a\* (redness) and + b\* (yellowness) values.  $\Delta E$  (total color difference) =  $[(L^* - L^* \text{ reference})^2 + (a^* - a^* \text{ reference})^2 + (b^* - b^* \text{ reference})^2]^{1/2}$ .

### *Sensory evaluation*

Mean sensory ratings for *akara* from differently milled samples are shown in Table 3.8. With the exception of oiliness, all samples had hedonic ratings of  $\geq 6$  (like slightly), indicating that consumers found them to be quite acceptable. The lower the oiliness rating, the less liked. Oiliness ratings for all samples ranged from 5.1 to 5.7 (neither like nor dislike), with consumers liking the less oily quality of *akara* from HM-1.73 slightly better than the other samples. HM-2.54 was acceptable to the largest number of respondents (91.25%), followed by PM-360 (85%) and WTM (82.5%). HM-1.73 was acceptable to 80% of the total panelists. These results indicate that *akara* that is comparable in sensory quality and acceptability to the traditional wet-milled product (WTM) can be processed from dry milled cowpeas.

The panelists were also asked to complete a questionnaire on fried food consumption and demographics during the session (Table 3.9). More than half (57.5%) of the respondents were female and 47.5% were 25-34 years of age. There were 37.5% respondents of Asian descent and 32.5% were white.

Twenty percent of the panelists ate fried foods at least once a day, 40% ate them once a week, and 40% ate fried foods twice a week. The most important desired trait in this food was said to be taste by a large number of respondents (55%). Surprisingly, nutrition was important to only 7.5% of the consumers. Texture was the other factor that was important to 20% of the consumers. Forty percent of the respondents ate away from home at least once a week and 35% of them, twice a week. About the same number of panelists said that they would expect to eat this kind of food in a restaurant (42.5%) or a fast food place (40%); the remainder (17.5%) were willing to try this product at home. A

large number (60%) of respondents said that fat content would affect their decision to consume this product; 35% thought fat content was not a factor. *Akara* was said to be appropriate for consumption as a side dish by 30% of consumers; 25% thought it would make a good appetizer, and 22.5% responded by saying that it could be a bread alternative. A majority (75%) of panelists said they would purchase the product as fully cooked frozen and then reheat it. Half of the remaining panelists (12.5%) said they would purchase it as a partially fried product to finish fry at home; the other half (12.5%) was willing to buy hydratable flour and cook it from scratch. Forty five percent of the respondents indicated that they liked *akara* better than hush puppies. On the other hand, 30% preferred hush puppies to *akara*. Half (12.5%) of the remaining panelists thought that *akara* was too different to compare to hush puppies whereas the other half (12.5%) liked them the same.

**Table 3.8.** Mean hedonic ratings for sensory quality and acceptability of *akara* prepared from differently milled cowpea samples <sup>1</sup>

Attributes		WTM	PM-360	PM-0	HM-2.54	HM-1.73
Appearance		7.4ab	7.1b	7.4ab	7.5a	7.1b
Color		7.5a	7.1b	7.3ab	7.6a	7.2ab
Aroma		7.2a	7.0ab	7.0ab	6.9ab	6.7b
Flavor		6.8ab	6.8ab	6.9a	6.9a	6.4b
Texture		6.9a	6.8a	6.6ab	6.7ab	6.3b
Oiliness		5.0b	5.1b	5.2ab	5.3ab	5.6a
Overall		6.7a	6.6a	6.6a	6.6a	6.3a
Acceptability %	YES	82.5	85	81.25	91.25	80
	NO	17.5	15	18.75	8.75	20

<sup>1</sup> a, b: Values in a row that are not followed by similar letter are significantly different ( $\alpha = 0.05$ ); WTM (wet mill), PM (plate milled samples at mentioned clearance in degrees) and HM (hammer milled samples at mentioned screen size in mm); Means for all sensory attributes and overall liking are based on a nine-point hedonic scale with 1 = dislike extremely to 9 = like extremely.

**Table 3.9.** Fried foods consumption pattern and demographic characteristics of consumers who evaluated *akara* from different milling treatments<sup>1</sup>

Question	% Respondents
1. How often do you eat fried foods ?	
Once a week	40
Twice a week	40
Once a day	20
Twice a day	0
More than twice a day	0
2. What is the most important trait you would desire in this food?	
Color	7.5
Taste	55
Texture	20
Aroma	7.5
Nutrition	7.5
Other	2.5
3. How often do you eat away from home?	
Once a day	12.5
Twice a day	10
Once a week	40
Twice a week	35
On weekends	2.5
4. Where are you most likely to eat this type of food?	
Fast food	40
Restaurant	42.5
Deli	0
Home	17.5
5. Would the fat content influence your purchasing decision?	
Yes	60
No	35
Not sure	5
6. In what way would you most likely eat this type of product?	
Snack food	20
Side dish	30
Appetizer	25
Bread alternative	22.5
Other	2.5

7. How would you purchase this product?	
Fully cooked frozen and reheated at home	75
Partially fried and finish fried at home	12.5
Hydratable flour and make from scratch	12.5
8. How do you like this product compared to hush puppies?	
More	45
Less	30
The same	12.5
Too different to compare	12.5

### Demographic Questions

1. What gender class do you belong to?	
Male	42.5
Female	57.5
2. What is your age group?	
18-24 years old	15
25-34 years old	47.5
35-44 years old	17.5
45-54 years old	17.5
55-64 years old	2.5
>64 years old	
3. What do you consider yourself to be?	
White	32.5
Black	10
Spanish/Hispanic	12.5
Asian	37.5
Other (please specify)	7.5

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<sup>1</sup> A total of 40 panelists answered the questions.

### *Conclusions*

The results from this study indicate that *akara* similar in quality to traditionally prepared (control) *akara* can be prepared from cowpea meal made from different milling and blending conditions. The manipulation of milling technique and blending time is an effective tool for producing similarities in particle size distributions of samples to result in similar paste functional properties; hence, a comparable quality product can be produced.

HM-2.54 produced a very good end product as can be seen from its high overall acceptability by consumers. Nutritionally, it had less fat than traditionally prepared *akara*, which is highly desirable. The performance of meals/flours is dependent upon their functional properties. Particle size distribution is one of the major factors influencing meal/flour functionality and hence the final product quality. *Akara* produced from fine flour had a tough and dense texture but produced product with a low fat content. The lack of sponginess in texture was responsible for its somewhat lower sensory ratings. The role of additional blending in determination of final product quality is apparent from the findings for HM-1.73. Additional blending of paste reduces the particle size distribution and thus aids in better moisture distribution in the sample. Further on, this translates into lower specific gravity of paste and hence better end product quality.

Cowpeas are a good source of protein and B-vitamins but are underutilized due to inconvenience in food preparation. This study demonstrates that dry milled meal can be used to produce *akara* that is comparable in quality to that made by the traditional wet

milling process. This will help in reducing *akara*'s preparation time and hence make this unique product more appealing to consumers.

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**SECTION IV**  
**SUMMARY AND CONCLUSIONS**

Particle size distribution (PSD) of cowpeas from various milling treatments provided insights into its affect on functional properties of paste produced from meals/flours. PM-360 produced the coarsest meal among all samples with a  $d_{gw}$  of 1558 microns. With a decrease in the clearance of the plate mill, the  $d_{gw}$  decreased. HM-1.73 produced the finest flour with a  $d_{gw}$  of 221 microns. All other samples had  $d_{gw}$  ranging between these two samples. Additional blending of pastes from the meals/flours resulted in a significant reduction in particle size for all samples. Larger samples such as PM-360 and PM-270 showed the largest reduction in particle size (87.40% and 81.16%, respectively) with further paste blending. Samples with smaller particle size such as HM-1.73 showed a reduction of only 24.06%, which was the least among all samples. Whipping did not have any significant influence on PSD of samples.

Additional paste blending also resulted in significant improvement in water holding capacity (WHC) for all samples. Before blending (BB), WTM had the highest WHC of 12.12 g/g. Large-sized gritty samples such as PM-360 showed the least WHC of 4.32 g/g. After blending (AB), the maximum improvement in WHC was found in the large-sized gritty samples. This was mainly attributed to conservation of the fiber structure and cell wall material during milling and their incorporation into the paste after blending. PM-360 showed an improvement of 315.51% over BB whereas HM-1.73 showed an improvement of only 89.62%. Whipping had a significant negative influence on some samples and this was attributed to particle coalescence.

Swelling capacity (SWC) showed a similar trend in all samples. The wet-milled control showed a high SWC of 22.7 mL/g before blending. HM-1.73 had the highest SWC (14.7 mL/g) before blending among the dry-milled samples. This was probably

because of increased surface area available for water absorption and swelling and also more fiber content due to intense milling. After blending, PM-360 showed an increase of 209.09% whereas HM-1.73 showed an increase of only 131.82%. Whipping further improved SWC for PM-360 and PM-0.

In the second part of the study, we selected two plate mill samples closest to the wet mill (WTM) control in terms of particle size distribution. The PSD of these samples was analyzed by varying paste blending times and comparing to WTM paste blended for 5 minutes. PM-360 blended for 4.5 minutes and PM-0 blended for 3.5 minutes showed the closest match to the control. WTM formed the most viscous paste after whipping (43800cp). PM-360 showed the highest reduction (54.19%) in viscosity after whipping whereas HM-1.73 showed the least (39.82%). Specific gravity also showed a similar trend. The sample with the lowest specific gravity formed more balls with lighter weight due to increased air incorporation. *Akara* prepared from WTM and PM-360 had the highest fat content of ~33.00%. The sample with the smallest particle size and highly viscous paste (HM-1.73) produced *akara* with low fat (14.65%) and high moisture. However, this sample had a tough and dense texture and received slightly lower sensory ratings than the other treatments. HM-2.54 received the highest sensory ratings, although all samples were acceptable. HM-2.54 has potential for marketing to American consumers as a reduced fat product. PM-360 made an excellent product that was comparable in quality to traditional wet-milled *akara* but was high in fat content. It can be a very good alternative for use in African nations where obesity is not a problem.

This study showed that milling has a significant affect on hydration properties of cowpea meals and hence the quality of the end product, *akara*. The efficacy of PSD as a tool for product matching and development was also demonstrated.

**APPENDICES**

### CONSENT FORM

I, \_\_\_\_\_, agree to participate in the research entitled “An Integrated Approach to Improve the Quality and Safety of Selected Foods” which is being conducted by Kay H. McWatters of the Department of Food Science and Technology of the University of Georgia, phone number (770) 412-4737.

I understand that participation is entirely voluntary and whether or not I participate will not affect how I am treated. **I can withdraw my consent at any time** and have the results of the participation returned to me, removed from the experimental records, or destroyed.

The following points have been explained to me:

- 1) The reason for the research is to gather information on consumer opinions of *akara* (fried cowpea paste). The benefit that I may expect from it is a satisfaction that I have contributed to solution and evaluation of problems relating to such examinations.
- 2) The procedures are as follows: Coded samples will be placed in front of me and I will evaluate them by normal standard methods (visual observation, smelling, and tasting) and indicate my evaluation on score sheets. All procedures are standard methods as published by the American Society for Testing and Materials.
- 3) Participation entails the following risks: The only risk which can be envisioned is that of an allergic reaction to blackeye peas, salt, onions, bell peppers or peanut oil. However, because the nature of the products will be known to me beforehand, the situation can normally be avoided. In the event an allergic reaction does occur unknown to the participants, medical treatment is available from the Spalding Regional Hospital.
- 4) It is my responsibility to make known to the investigators any allergies I may have toward the food products being tested when they occur. The food to be tested is *akara* containing the following ingredients: blackeye peas, salt, onions, bell peppers and peanut oil. **Allergies:** \_\_\_\_\_)
- 5) The results of this participation will be confidential and will not be released in any individually identifiable form without my prior consent unless required by law.
- 6) The investigators will answer any further questions about the research, either now or during the course of the project.

\_\_\_\_\_  
Signature of Investigator

\_\_\_\_\_  
Signature of Participant

Date: November 21, 2002

Witness: \_\_\_\_\_

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PLEASE SIGN BOTH COPIES OF THIS FORM. KEEP ONE AND RETURN THE OTHER TO THE INVESTIGATOR.

Research at The University of Georgia, which involves human participants, is carried out under the oversight of the Institutional Review Board. Questions or problems regarding these activities should be addressed to Dr. Christina Joseph, Coordinator, Human Subjects Research, Institutional Review Board, Office of Vice President for Research, The University of Georgia, 604A Graduate Studies Research Center, Athens, Georgia, 30602, (706) 542-6514.

Revised 12/20/02

Panelist Code: \_\_\_\_\_ Sample Code: \_\_\_\_\_ Date: \_\_\_\_\_

Please evaluate this product and check the space that best reflects your feeling about the product for all 8 questions.

1. How would you rate the **appearance** of the sample?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. How would you rate the **color** of the sample?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. How do you like the **aroma**?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

4. How would you rate the **flavor**?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. How do you like the **texture** of the sample?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. How would you describe the **oiliness** of the sample?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

7. How would you rate your **overall liking** of this sample?

Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like Extremely
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. Is this product **acceptable**?

Yes  No