MANIPULATION OF PROCESSING VARIABLES FOR IMPROVED FUNCTIONALITY OF COWPEA (Vigna unguiculata) MEAL FOR USE IN MAKING

AKARA (fried cowpea paste)

by

MELISSA VANCHINA

(Under the Direction of Manjeet Chinnan)

ABSTRACT

Importance of particle size distribution (PSD) in conjunction with milling method (wet or dry) on the functionality of cowpea paste and the quality and acceptance of akara was investigated for dry milled hammer milled meal (HM) and wet-milled freeze-dried meal (FD). Optimal PSD for both HM and FD meals proved to be 65% medium particles (0.180 – 0.425 mm) and 35% large particles (0.425 – 1.000 mm) with paste made from these meals having good handling characteristics. Akara produced from the two meals had hardness values not significantly different from traditionally prepared (WTM) akara (WTM: 5.341 N, HM: 5.317 N, and FD: 4.048 N). Image analysis of scanning electron micrographs of akara crumb structure showed no significant difference in the amount of air incorporated into the three samples. Sensory panelists reported no significant difference in sensory attributes and overall liking among the three akara samples.

INDEX WORDS: cowpea, *Vigna unguiculata*, akara, cowpea meal, particle size distribution, functional properties, texture, sensory evaluation

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B.S., The University of Alabama at Birmingham, 1999

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial

Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

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DEDICATION

My work in this thesis is dedicated to my grandfathers, John Vanchina and George Keith—the two men who have taught me the value of an education and the meaning of hard work.

ACKNOWLEDGEMENTS

I must first thank Dr. Chinnan for his extraordinary patience and guidance throughout this process. I would also like to thank my committee members, Dr. Phillips, Dr. Hung and Kay McWatters, for their assistance in completion of this work. In addition, I owe thanks to several technicians and staff members in the Department of Food Science and Technology in Griffin, GA: Hannah Smith, Glenn Farrell, Sue Ellen McCullough, Sandra Walker, Chun Fang, Barbara Presley, and Joy English. I am grateful to each of these individuals for contributing to the completion of this work with either technical or personal expertise.

Thanks are also extended to the Bean/Cowpea Collaborative Research Support Program, U.S. Agency for International Development for funding both this research and my education.

I thank my friends and family, all of whom supported this effort and were there for me when I needed them. Mostly though, I thank my mom for the courage to pursue this goal.

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INTRODUCTION

Vigna unguiculata, known internationally as the cowpea and as the black-eyed pea in the United States, is a highly nutritious low-cost legume indigenous to Africa and grown today in tropical climates worldwide. Cowpeas are an excellent source of protein, fiber and B-vitamins. Due to their high lysine content, combining cowpeas with cereals provides high quality, complete protein in diets lacking animal protein sources. The legume, eaten daily by many West Africans, is consumed as a vegetable, incorporated into many diverse recipes, and is processed into a variety of products. One such product very popular in West African nations is akara, which is deep fried whipped cowpea paste seasoned with salt, chopped onion, and hot or bell peppers. Akara is often consumed as a breakfast food or throughout the day as a snack. It is prepared in the home and purchased fully cooked from vendors in marketplaces. Traditional akara preparation from the whole cowpea can take up to several hours, and paste cannot be held for long without detriment to the quality of the product and potential food safety hazards.

The popularity of akara combined with the time-consuming and labor-intensive preparation have led to the development of commercially available readily-hydratable cowpea meals and flours. Although the meals and flours meet the requirement of being convenient, they produce akara that is considered inferior to traditionally prepared akara and is unacceptable to consumers. Cowpea flours have been shown to have poor hydration characteristics, and akara prepared from flour is dense, has a hard outer crust, and lacks the fresh beany taste savored in traditionally prepared akara. The formation of

a good foam in the whipping process is essential to a spongy end product desired by consumers, and foam formation is dependent on the functionality of the various components of the cowpea seed. Cowpea meal or flour with satisfactory functionality will not only find use in traditional products such as akara, but may also foster usage of cowpea in new markets and for new purposes.

Extensive research has been conducted in the past on almost every facet of the cowpea and how it pertains to making acceptable akara in order to aid in development of a functional cowpea meal or flour. Based on data from the past studies, it can be concluded that there are three keys to making acceptable akara: 1) cowpea proteins must maintain their natural conformation, 2) particle size distribution of meal or flour must consist of at least 65% particles that fall in the medium size range, i.e. between 0.180 and 0.425 mm, and 3) chunks of cell wall matrix must be present after processing. Although each of these factors is known to be essential and it is assumed they are confounding, the degree of importance of each factor within the whole system is not well understood. Therefore, it was the objective of this study to determine the importance of thermal abuse, particle size distribution, and wet versus dry milling in the processing of dry cowpea meal. This was accomplished by processing meal using different methods in order to isolate the influence of each variable and examine its effect. The resulting meals were evaluated to measure functionality of the pastes and acceptance of akara made using the treatment meals.

For this study, two different cowpea meals were prepared from California Cream variety cowpeas: a freeze dried meal processed by wet-milling undecorticated cowpeas, freeze drying the paste, and plate milling the dried paste to form a coarse meal, and a

hammer milled meal processed by dry-milling undecorticated cowpeas using a hammer mill. Opting to process a meal via freeze drying allowed for the examination of a meal that was wet milled and dried without heat. Freeze drying is a relatively gentle drying process employed to minimize degradation caused by thermal processing and maintain the attributes (chemical, biological, physical and organoleptic) the product has in the fresh state. Preliminary work showed an emphasis on the particle size distribution of the meals over the milling method used in processing. Section III of this study examined the importance of particle size distribution of the differently processed cowpea meals on essential cowpea paste functional properties used as indicators for making acceptable akara, i.e. viscosity of paste prior to and following whipping, specific gravity of paste prior to and following whipping, and texture of akara. In Section IV, the meal pastes with the best functionality as determined by the work reported in Section III were further studied. Direct quality indicators, i.e. particle size distribution of the pastes at the various stages of akara making, and micrographs of prepared akara, were examined. In addition, acceptance by a sensory panel of akara made from the meal pastes was measured.

SECTION I

LITERATURE REVIEW

Cowpea

Vigna unguiculata, a legume commonly known as the cowpea, is an important dietary staple in West African nations because of its high nutritional value, low cost and broad availability in the region (Boeh-Ocansey, 1989; Prinyawiwatkul, McWatters, Beuchat, & Phillips, 1996; Uzogara & Ofuya, 1992). Once known as "poor man's meat" in many regions, the perception of the cowpea has shifted somewhat in the last 15 years. In Nigeria, the legume is now generally considered a health food consumed by the rich and informed more than the poor (Nnanyelugo, Ngoddy, Okeke, & Ngwu, 1997). Cowpeas are eaten as a vegetable, often in combination with cereals or grains, are incorporated into a variety of recipes and are processed into various products. The leaves, fresh peas, and green pods are also consumed as vegetables (Ahenkora, Adu Dapaah, & Agyemang, 1998; Nielsen, Ohler, Mitchell, 1997). Cowpea is a starchprotein, rather than an oil-protein, seed which allows it broader application when compared to other common West African legumes (Henshaw, McWatters, Oguntunde, & Phillips, 1996). Cowpeas, often used for fodder in addition to or rather than as human food, are grown in over two-thirds of the developing world (Tarawali, Singh, Peters, & Blade, 1997), and are consumed as a major dietary protein in many developing countries (Abdalla, Elkhalifa, & Eltinay, 2001). However, the pulse is indigenous to Africa and the great majority of the world's cowpea supply is grown and consumed locally in West Africa (Boeh-Ocansey, 1989).

Intrinsic characteristics of *Vigna unguiculata* make it an ideal crop for semiarid regions with somewhat poor soil (Rachie, 1985). It is shade tolerant and fixes nitrogen, which improves the nitrogen content of the soil leading to improvement in the soil's

fertility (Mortimore, Singh, Harris, & Blade, 1997; Rachie, 1985; Singh, B.B., 2003). Cowpea is well-suited for use in intercropping systems with a variety of plants such as millet and sorghum. According to the Food and Agriculture Organization of the United Nations, the most recent estimate for worldwide production of dry cowpeas is 3.89 million Mt, with 2.2 million of that coming from Nigeria (www.fao.org). The legume is considered internationally important, but has limited popularity in the United States, where it is known commonly as the black-eyed pea, and is consumed mostly in the southeast as a boiled vegetable (www.jeffersoninstitute.org). The U.S. is the leading producer of cowpeas among developed nations, although the crop is grown mainly as a cover crop and for forage (Prinyawiwatkul et al., 1996; Rachie, 1985).

Nutrient Composition

Cowpeas consist of 24% protein (Bressani, 1985; Phillips & McWatters, 1991) consisting of mainly globulins (66.6%) and albumins (24.9%) (Chan & Phillips, 1994). Chan and Phillips (1994) demonstrated that cowpeas are rich in lysine and deficient in sulfur-containing amino acids. This amino acid composition makes cowpea an ideal dietary complement to cereals, which are rich in sulfur-containing amino acids and low in lysine. The nutritionally synergistic combination of amino acids found in cereals and legumes provides high quality protein in diets that are lacking animal protein sources (Damodaran, 1996; Singh, Ajeigbe, Tarawali, Fernandez-Rivera, & Abubakar, 2003). Cowpeas contain approximately 60% carbohydrates and are an important source of dietary fiber as well as several water-soluble vitamins (mainly B-vitamins) (Phillips, 1993). Cowpeas are also an excellent source of folate with 100g having the ability to provide over 350% of the Recommended Daily Allowance. Adequate folate intake has

gained a good deal of attention in recent years to prevent neural tube birth defects and aid in the prevention of heart disease (Rader, Weaver, & Angyal, 2000; Voutilainen et al., 2004).

Factors Limiting Use

Although cowpeas are a nutritious and inexpensive food source, they remain underutilized in many regions of the world due to a variety of reasons. One such reason, which affects consumption in areas where the cowpea is popular, is the Hard To Cook (HTC) defect. The HTC defect commonly occurs due to sub-optimal storage of the legume at high temperatures and/or high humidity for several months. The HTC defect causes the majority of the proteins in cowpeas to change from water-soluble to waterinsoluble, and the peas remain hard after normal cooking requiring either additional processing or prolonged cooking prior to consumption (Liu, Phillips, Hung, Shewfelt, & McWatters, 1992). In addition to the HTC peas being unappetizing due to textural changes, Tuan and Phillips (1992) found that the cowpeas with HTC defect are nutritionally inferior to normal cowpeas. Researchers also found cowpeas that have been stored at a high temperature, 35° C, performed poorly when used to make traditional West African cowpea products in comparison to cowpeas stored at optimal temperatures, 2 and 21° C (McWatters, Chinnan, Worthington, & Beuchat, 1987). Hung, McWatters, Phillips, Beuchat, and Chinnan (1995) found that cowpea meal made from HTC cowpeas had significantly lower protein solubility and water absorption. The researchers attempted to compensate by varying processing conditions used to make a fried cowpea paste product from the HTC meal and were unsuccessful. The paste produced from HTC

meal was difficult to dispense in frying oil and resulted in a dense end product unacceptable to consumers.

There are also anti-nutritional factors found in cowpeas that negatively influence their consumption. Flatulence is often associated with legume consumption. Humans lack the necessary enzyme, specifically alpha-galactosidase, in their digestive tract to hydrolyze low molecular weight oligosaccharides found in cowpeas such as raffinose, stachyose and verbascose (Phillips et al., 2003). As a result, these oligosaccharides pass undigested into the small intestine where they ferment and produce gas and discomfort (Sosulski, Elkowicz, & Reichert, 1982). The main flatulence-causing sugars, those of the raffinose family, are water-soluble and are therefore mostly removed when water used to soak and/or cook cowpeas is discarded (Uebersax & Ruengsakulrach, 1989). Controlled germination of cowpea seeds has been studied as a method for the reduction of oligosaccharides in cowpeas. The researchers found a reduction in flatulence-producing saccharides when seeds were germinated for 24 h at 30° C (Nnanna & Phillips, 1988). However, Uwaegbute, Iroegbu, and Eke (2000) concluded that overall acceptance of traditional African cowpea products decreased with increasing germination time.

Additional anti-nutritional factors include trypsin inhibitors and tannins, which are known to inhibit digestive enzymes negatively affecting protein digestibility (Plahar, Annan, & Nti, 1997). Tannins are almost entirely eliminated via decortication, and trypsin inhibitors are heat labile molecules that can be destroyed when subjected to moist heat at >100° C and >20% moisture (Phillips et al., 2003).

Utilization of Cowpeas for Food

Uses of cowpeas in diets across the globe vary widely. The primary mode of consumption in the United States is as a boiled vegetable, which is popular in southeastern states but rarely consumed in other regions of the country. In tropical and subtropical regions where the cowpea is a crucial component of the diet (Akpapunam & Markakis, 1981a), the legume is included in casseroles, stews, soups and salads, is processed into steamed or fried dishes, is roasted for snacking, and is often combined with other staple products of a given area to provide high quality protein to the diet. Such staples often include plantains, bananas, maize, cassava, yam, sweet potatoes and rice (Nnanyelugo et al., 1997; Uzogara & Ofuya, 1992). A variety of deep-fat fried, whipped cowpea paste dishes with various seasonings-akara, awon, seke-sin and kengbe, and steamed cowpea paste dishes with various seasonings—ekuru, moin-moin, jogi, ikoko and apapa can be processed from cowpeas. Cowpeas are also processed into dumplings known as dan wake and cowpea porridge with various seasonings (Dovlo, Williams, & Zoaka, 1976; Uzogara & Ofuya, 1992). A nutritious and easily digestible traditional African weaning food, known as leki, adayi or awolo-awolo, is made from decorticated cowpeas that are soaked and cooked until very soft then mashed and lightly seasoned (Dovlo et al., 1976).

Research conducted for the United States Agency for International Development and funded via the Bean/Cowpea Collaborative Research Support Program (CRSP) over the last 24 years has investigated many novel uses for cowpeas in both traditional foods, such as those mentioned above, and non-traditional foods. Composite flours which include cowpea flour have been used to make a number of products such as doughnuts,

breads, muffins, and tortillas. In all cases, cowpea flour was found acceptable in the given application when the optimal formulation and processing method was identified (Holt, Resurreccion, & McWatters, 1992a; Holt, Resurreccion, & McWatters, 1992b; McWatters, 1986; Phillips et al., 2003). Snack foods including extruded snacks and snack chips have been researched as inventive and novel products to increase cowpea consumption (Phillips et al., 2003). Snack chips made from cowpea, cornmeal and wheat flour were positively received by West African consumers, but not by American consumers unfamiliar with the cowpea flavor (Ward, Resurreccion, & McWatters, 1998). CRSP researchers have also examined cowpeas as an ingredient in weaning foods for economically challenged countries in need of highly nutritious foods for malnourished children. Mensa-Wilmot, Phillips, and Hargrove (2001) found that composite weaning mixtures containing cowpea and maize with either soybean or peanut flours that were extrusion cooked supplied adequate protein for weaning children. Mothers of weanling children in Ghana found the weaning foods containing cowpea acceptable, and considered the use of a local staple appealing (Mensa-Wilmot, Phillips, & Sefa-Dedeh, 2001).

Akara

Akara is a traditional African product made by deep frying cowpea paste that has been whipped and seasoned with salt, chopped onions and peppers. The outer crust of akara is crisp and the interior is spongy and bread-like. Akara is considered to be the most commonly consumed cowpea derived food in West Africa (Dovlo et al., 1976). It is often eaten as a snack food throughout the day or for breakfast (Uzogara & Ofuya, 1992). In West Africa, the customary serving size for an adult is approximately 100g

(McWatters, 1983). Akara is made by individuals in the home for the family and sold fully prepared by vendors in marketplaces (Phillips & McWatters, 1991). The traditional process for making akara is very time consuming and labor intensive. Dried cowpeas are first soaked in water in order to soften them and loosen the seed coat. Manual decortication then removes the seed coat, which contains any pigmentation, and reveals the creamy white cotyledon. Light-colored akara produced by using only the pigmentfree cotyledon is considered more acceptable than dark-colored akara by African consumers (Phillips et al., 2003; Uzogara & Ofuya, 1992). The softened cotyledons are wet-milled to form a paste. The paste is whipped and seasonings (salt, chopped onion and chopped hot or bell peppers) are incorporated. The whipped paste is dispensed into hot oil and deep-fried until golden brown. Depending on the equipment available, this process could take up to several hours and require manual labor on the part of the preparer (Dovlo et al., 1976). In addition, microbial spoilage necessitates that the paste be used within a few hours or be discarded meaning paste cannot be prepared ahead of time and stored for future use (Bulgarelli, Beuchat, & McWatters, 1988). Bulgarelli and Beuchat (1990) showed a steady increase in lactic acid bacteria populations of inoculated and uninoculated cowpea paste over time. At ambient tropical temperatures (30° C) , fermentation due to the lactic acid bacteria will occur. The authors note that fermented paste is not desirable for making akara.

Functional Properties Necessary for Acceptable Akara

Functionality is broadly defined as the properties of a particular food component that allow it to interact and react with other food components resulting in desired sensory characteristics in the end product. Functionality is affected by chemical changes as well

as physical changes to the components of a food and the system as a whole (Sikorski, 1997). The unique combination of cowpea proteins, starch and dietary fiber allow for whip-ability of cowpea paste resulting in the foam fundamental to producing acceptable akara (McWatters, 1985). The production of a good foam results in a spongy end product that is highly desired by consumers (Enwere, McWatters, & Phillips, 1998). An amalgam of growing, storage, and processing conditions, as well as genetic variety, influences the functional properties of legume components (Kaur & Singh, 2005). *Proteins*

Proteins are very versatile organic polymers that are either responsible for or contribute to many essential processes in food systems. Proteins play a role in viscosity, emulsification, foaming, water binding, and fat and flavor binding. The proteins found in cowpeas serve many purposes in paste and subsequent akara preparation. During the incorporation of air into the cowpea paste, proteins act as surfactants by quickly absorbing water at the water-air interface and undergoing a rapid rearrangement to form a viscoelastic film around the air bubbles (Damodaran, 1994). In addition, they increase the viscosity of the paste. Viscosity of the liquid phase of a foam plays a role in the stability of that foam over time. A more viscous paste results in smaller bubbles forming during whipping, and subsequently less liquid drains allowing the foam to hold up longer (Damodaran, 1994; Hanselmann & Windhab, 1999; Sikorski, 1997).

However, proteins are somewhat delicate, and their functionality depends on physical structure and physico-chemical characteristics, which are easily altered in many proteins (Damodaran, 1996; Giese, 1994; Marsili, 1993). In food systems, insoluble proteins offer few uses, and foaming and thickening are especially affected by the loss of

solubility (Giese, 1994). Solubility of cowpea and other legume proteins has repeatedly been shown to be lowered by heat processing (Abbey & Ibeh, 1988; Enwere & Ngoddy, 1986; Giami, 1993; Henshaw & Lawal, 1993; Nagmani & Prakash, 1997; Phillips, Chinnan, Branch, Miller, & McWatters, 1988). Prepared paste left at ambient tropical temperatures (30° C) will ferment due to lactic acid bacteria. The resulting lowered pH will decrease the solubility of the proteins thus decreasing the foamability of the paste (Bulgarelli & Beuchat, 1990). Phillips et al. (1988) demonstrated that changes seen in the viscosity and specific gravity of cowpea paste, both characteristics related to the quality of the foam, paralleled changes seen in the solubility of cowpea proteins. Qualitatively speaking, cowpea paste produces the best akara when used immediately after whipping, but still produces acceptable akara up to 60 min after whipping (Hung & McWatters, 1990). Foam stability is influenced by the rheological properties of the protein film formed during foaming, and is dependent on different properties than foaming itself indicating that a combination of proteins or additional food components are necessary to ensure both good foam formation and a stable foam over time (Damodaran, 1996; Sikorski, 1997).

Hydration Characteristics

In addition to the foaming of cowpea paste, the hydration characteristics of the starting material and resulting flow characteristics of the paste influence the final appearance and texture, and hence the acceptability, of akara (McWatters & Brantley, 1982). Cowpea paste consistency is dependent on the ability of the starting material to adequately absorb water. Starting material with a low level of hydration has been shown to result in a dry dense product with a tough outer crust (McWatters, 1983). McWatters

and Chhinnan (1985) demonstrated that the water level and the combination of water level-hydration time significantly affected the apparent viscosity of cowpea paste with water level being the more influential variable. McWatters (1983) found poor functionality due to inferior water binding by commercially processed Nigerian cowpea flour was a result of the small particle size of the flour. This conclusion is supported by work of several other researchers who found that hydration improved with increased particle size (Kerr, Ward, McWatters, & Resurreccion, 2000; Ngoddy, Enwere, & Onuorah, 1986). Phillips et al. (1988) pointed out that water absorption of cowpea meals and flours is more than a physical phenomena related to particle size. Proteins are known to play an important role in the water absorption and holding capacity of a food system (Giese, 1994; Sikorski, 1997). Kerr et al. (2000) showed a correlation between a decrease in water absorption, a decrease in particle size and a decrease in protein content. Sefa-Dedeh and Stanley (1979) examined the microstructure of several cowpea cultivars and observed the water absorption of those cultivars. The authors determined that water uptake in cowpeas is attributed to several characteristics and cannot be easily attributed to one component of the seed.

Methodologies for Evaluating Cowpea Paste

Specific Gravity

Specific gravity of a substance is the ratio of the mass of a specific volume to the mass of the same volume of distilled water. The percent change in specific gravity of cowpea paste after the paste has been whipped is used as an indirect indicator of foaming ability as it expresses the amount of air incorporated into the paste. Campbell, Penfield, and Griswold (1979) describe the method for measuring specific gravity of materials.

The container used for the measurement was filled with room temperature boiled distilled water and weighed. The material was then gently spooned into the dried container. The container was gently tapped to remove air bubbles, the container was then leveled using a spatula and wiped clean before weighing. Specific gravity is determined using the following equation: Specific Gravity = (weight of filled container – weight of container)/(weight of water filled container – weight of container).

Hung, McWatters, and Chinnan (1988a) developed a direct method for quantifying the amount of air in a foam sample by observing and photographing whipped cowpea paste at 100X under a bright field microscope. The ratio of the volume occupied by air bubbles to the total volume was expressed mathematically, and the researchers concluded that the direct measurement of the air in a cowpea paste foam correlated closely with indirect measures of foaming ability such as specific gravity. Therefore, indirect measures of foaming ability are relied on by researchers to express foamability. *Viscosity*

Viscosity of cowpea paste, both before and after whipping, can be used as a determinant of the functionality of the paste. Chhinnan, McWatters, and Rao (1985) detailed a method for determining viscosity of cowpea paste using a Brookfield Viscometer equipped with a Helipath Stand and a TB spindle. Viscosity measurements were taken at 23° C and 5 rpm. Kethireddipalli, Hung, McWatters, and Phillips (2002a) modified the method by increasing to 10 rpm and using the TB spindle only for the more viscous control paste and a TA spindle for the less viscous experimental pastes. Patterson, McWatters, Hung, Chinnan, and Phillips (2002) again modified the procedure by using a TC spindle for all measurements.

Wet Particle Size Distribution

Singh, Hung, Phillips, Chinnan, and McWatters (2004) developed a method for wet particle size distribution measurements of cowpea paste using a Malvern Instruments Mastersizer which utilizes laser diffraction. Cowpea paste samples were prepared. After blending and again after whipping, 1 g of each paste sample was diluted in 100 mL deionized water. The diluted sample was then loaded into the volume presentation unit of the instrument, which contained 120 mL of deionized, water until the obscuration level reached 13%. Overall particle concentration is indicated by the obscuration level which is the faction of light lost from the main beam. The Malvern optical mode calculated the relative volume distribution of particles and other size distribution parameters from the light scattering data assuming an equivalent sphere. The author then used the ASAE Standard S319 to calculate the geometric mean diameter and geometric standard deviation of sample estimate.

Methodologies for Evaluating Akara

Texture

Friedman, Whitney, and Surmacka Szczesniak (1963) defined the texture profile of foods (hardness, cohesiveness, elasticity, adhesiveness, brittleness, chewiness, and gumminess) by deriving a force-deformation curve (referred to as a texturometer curve by the authors) via measurement of force necessary to compress food samples within a given set of parameters. Hardness was defined in the research as the height of the first peak on the force-deformation curve divided by the volts input. Cohesiveness was defined as the ratio of the area under the second peak and the area under the first peak. Hung, Chinnan, and McWatters (1988b) outlined a compression test for determining the

texture of akara using an Instron Universal Testing Machine with flat plates. The crust of akara was removed, and a 1 cm cube was cut from the crumb using a sharp knife. The cube was then compressed twice to 25% of its original height at a crosshead speed of 50 mm/min and a chart speed of 200 mm/min. The hardness equation of Friedman et al. (1963) was then used to calculate harness.

Sensory Evaluation

McWatters (1983) used a sensory panel to evaluate akara made from whole peas and Nigerian cowpea flour. The panelists were served whole akara balls reheated from the frozen state and rated them using a hedonic scale of 9 to 1 with 9 being excellent, 5 being borderline and 1 being very poor. The akara was rated on appearance, color, aroma, texture and flavor. In subsequent experiments, McWatters and other researchers found reheating akara at 204° C on a cookie sheet spaced approximately 115 mm apart for 6 min from a refrigerated temperature of 4° C was the most efficient and effective way to serve multiple samples to a sensory panel for evaluation (personal communication).

Scanning Electron Microscopy (SEM)

Akara with a crumb that is spongy and light is preferred by consumers. Enwere et al. (1998) developed a method for preparing akara sections for SEM examination. Two mm thick sections of akara were cut using a sharp knife. The sections were then mounted with colloidal silver paint on SEM stubs and freeze dried for four days. The dried akara sections were coated with 70 nm gold palladium and micrographs were taken at an accelerating voltage of 20KV using a Phillips 505 X scanning electron microscope. In a personal communication with Dr. John Shields, Director of the University of Georgia's

Center for Ultrastructural Research, the procedure was altered to fast freezing a sliver of akara mounted on a SEM stub in liquid nitrogen then sublimating the sample, and coating with gold palladium.

Cowpea Flour and Meal

To foster cowpea usage for traditional and novel products in traditional as well as new markets, easy-to-use readily-hydratable cowpea flours and meals were developed. Flours currently available on the commercial market meet the requirement of being convenient but do not produce end products on par with freshly prepared products. Akara prepared from commercially available flours was without typical and desired fresh cowpea flavor and had a dense, dry texture (Dovlo et al., 1976; McWatters, 1983). A great deal of research with the aim of improving cowpea flour and meal performance has been conducted over the past couple of decades. There are several potential variables in the processing of cowpea flour that ultimately influence functionality including decortication method, drying temperatures, milling method and mill screen size, germination of seeds, and fermentation of seeds. The functional properties, i.e. waterabsorption, foaming and flow characteristics, of paste made from hydrated meal or flour determine its acceptance as a starting material for akara (Phillips & McWatters, 1991).

Processing Variables

Thermal Treatments

When being milled, cowpea cultivars with pigmented seed coats must first be decorticated in order to prevent undesirable dark specs in the flour (Onayemi & Potter, 1976). Dry-milling of cowpeas for flour and meal production is preferable to wet-milling to minimize microbial growth and energy input required (Phillips & McWatters, 1991).

In addition, water conservation is important in many areas producing and utilizing cowpea flour (Akpapunam & Markakis, 1981b). However, dry decortication of unconditioned cowpea seeds leads to some loss of the soft cotyledon, therefore preconditioning of the seeds via wetting and thermal drying prior to decortication is often employed to remove the seed coat with minimal loss (Phillips & McWatters, 1991). Ngoddy et al. (1986) used a systematic approach to look at the influence of the main processing variables in cowpea flour production on akara produced from the flour. The researchers found that drying temperatures ≤60° C did not negatively affect the functional properties of flour significantly enough to make it unacceptable for use in making akara. As the drying temperature increased, the paste steadily lost its foaming capacity and would sink when dispensed in frying oil resulting in distorted akara balls. Similar results were seen in several other studies conducted by other researchers (Abbey & Ibeh, 1988; Hung et al., 1988b; McWatters, Chinnan, Hung, & Branch, 1988). McWatters et al. (1988) found that as the drying temperature used to process cowpea meal was increased, the apparent viscosity of the prepared pastes also increased. Thermal processing of cowpea flour has also been demonstrated to cause an increase in oil absorption (Abbey & Ibeh, 1988; Giami, 1993; Henshaw & Lawal, 1993). Singh et al. (2004) showed that akara perceived as less oily was preferred by sensory panelists.

Function follows form with proteins, and thermal denaturation leads to a number of changes including a loss of solubility and changes in binding characteristics (Kinsella, 1984). Phillips et al. (1988) established that certain cowpea albumin fractions, which are proteins essential in the foaming of cowpea paste, were denatured at temperatures above 70° C. By precipitating cowpea globulins (water-insoluble proteins), Enwere et al.

(1998) showed that heat treatments up to 120° C had little effect on the conformation of globulins. Nagmani and Prakash (1997) subjected several legume flours (bengal gram, black gram, green gram and lentils) to thermal treatments. The researchers observed that as heat increased all flours tested had a decrease in protein solubility affecting functional properties, which they attributed to the denaturation of proteins. Nitrogen solubility also decreased with increasing heat treatments in wing bean flour (Narayana & Narasinga Rao, 1982). Enwere and Ngoddy (1986) demonstrated a decrease in water absorption, swelling capacity, whip-ability, foaming and foam stability in cowpea flours processed with drying temperatures above 60° C. Hung et al. (1988a) examined cowpea paste microscopically and observed that whipped paste made from flours subjected to thermal treatments below 70° C had an air bubble distribution similar to that seen in control paste made from wet-milled fresh cowpeas, whereas whipped paste made from flour heated to 110° C had a lower number of bubbles. SEM micrographs of akara produced from flour made from cowpeas dried at 30° C showed a spongy texture with large air cells. At 80° C, the micrograph showed a less-spongy texture with fewer and smaller air cells, and at 120° C, the akara completely lost a spongy appearance (Enwere et al., 1998).

The use of cream variety cowpea cultivars with little or no pigmentation in the seed coat eliminated the need to decorticate seeds prior to milling. Cowpea paste made from non-decorticated cream variety cowpeas has shown paste handling characteristics similar to paste made from decorticated peas (McWatters, 1983; Prinyawiwatkul, McWatters, Beuchat, & Phillips, 1994), and akara made from undecorticated seeds has been found acceptable by sensory panelists (McWatters, 1983; McWatters & Brantley, 1982; McWatters & Flora, 1980; Patterson et al., 2002). The elimination of decortication

is one option for minimizing thermal abuse to which cowpeas may be subjected during processing.

Particle Size Distribution (PSD)

Particle size of plant fibers is an important factor in the water binding properties of that fiber. Reduction in particle size of wheat bran led to decreased water absorption and a decrease in specific volume of the wheat bran when hydrated. The researcher attributed these phenomena to the finer particles being less porous as well as a collapse of the cell wall matrix structure in the particles caused by shearing during milling (Cadden, 1987). Mongeau and Brassard (1982) saw a decrease in water holding capacity of wheat fiber as particle size was reduced and attributed this to the physical change in the matrix structure upon grinding. Han and Kahn (1990a and b) milled and fractionated chickpeas and pinto and navy beans and found the fractions with a larger particle size (17.8 μ m mean particle size) had superior water-holding capacity. Auffret, Ralet, Guillon, Barry, and Thibault (1994) examined the hydration properties of wheat bran, pea hulls, sugarbeet, and citrus fibers after grinding and under various experimental conditions and concluded that the observed decrease in water-holding capacity with decreasing particle size was most likely due to the alteration of the physical structure of the fiber matrix. Dietary fiber left after the production of coconut milk was shown to have decreasing hydration properties with decreasing particle size (Raghavendra, Rastogi, Raghavarao, & Tharanathan, 2004).

Robertson, de Monredon, Dysseler, Guillon, Amado, and Thibault (2000) found that plant fiber samples with smaller particles allowed for more dense packing of particles, which logically would lead to a denser end product. The researchers concluded

that, in addition to the physical arrangement of the particles, the structure of the particles themselves after milling influenced the hydration characteristics of that fiber. As mentioned previously, McWatters (1983) attributed the lack of proper functionality of Nigerian cowpea flour and the resulting dense and tough akara to small particle size. Upon sieving, 47% of the Nigerian flour's particles were collected from a #400 sieve (0.038 mm mesh opening) compared to only 16% of particles in traditionally prepared paste. It was necessary for the researcher to lower the amount of water added to the flour recommended by the manufacturer in order to achieve a paste that was viscous enough to dispense in frying oil. In addition, as recommended by the manufacturer, an egg had to be added to the recipe. To further investigate the influence of particle size on paste characteristics, the researcher milled cowpea flour using a series of screens, 2.0 mm, 1.0 mm, and 0.5 mm. As the mill screen size decreased, the pastes became less viscous and more difficult to handle. Kerr et al. (2000) produced three cowpea flour samples using 2.0, 1.0 and 0.5 mm screens, fractionated the samples via sieving and evaluated the unsieved flours and the various particle size fractions. With the exception of starch, very little variation was seen in the proximate composition between the unsieved flours and the same particle size fractions from the three mill screens. Water absorption was seen to decrease in the unsieved flour samples as screen size decreased. However, water absorption of same particle-sized fractions from the three different mill screens showed no significant difference. Although oil absorption increased slightly as the mill screen size decreased, the differences were not statistically significant. Protein solubility increased as the mill screen size decreased. Midsized particles (those collected from 0.149 mm mesh screen sieve) had high water absorption and were high in protein content

leading the researchers to conclude that the proteins in cowpea are responsible for a significant degree of paste hydration.

Singh et al. (2004) examined the PSD of traditionally wet-milled cowpea paste and pastes made from differently milled cowpea meal and flour samples throughout the akara-making process using laser diffraction. Manipulating paste preparation methods was shown to play a role in functionality as blending of paste further reduced particle size (Singh, 2003). The researcher milled several samples using either a hammer mill or plate mill, and then blended the hydrated meal samples for varying times in a kitchen blender. Using PSD of traditionally wet-milled paste blended for 5 min as the benchmark, the researchers determined the optimal blend times for the variously milled samples and then evaluated the functionality of the resulting pastes. The PSD of the sample milled with a 360° clearance on a plate mill and blended for 4.5 min was not significantly different from that of traditionally wet-milled paste after the pastes were whipped. The measured hardness of akara made from those two samples, 6.80 N and 6.44 N respectively, were also not significantly different. Meal that was not further blended prior to whipping produced a very hard akara ball with a hardness measurement of 13.64 N compared to 6.44 N for the traditionally prepared akara from wet-milled paste (Singh et al., 2004).

Ngoddy et al. (1986) produced flours of varying particle sizes and found that as the flour particle size decreased, it was necessary to decrease the water in order to obtain a paste that was viscous enough to be dispensed for frying. The researchers produced flour by milling through a 1 mm screen for 1 to 5 passes. In all of the samples, a significant proportion of the particles were classified as fine; those retained on the #200 sieve (0.075 mm mesh opening) after sieving ranged from 22.23 to 46.40%. The

distribution of particles retained on the larger mesh opening sieves decreased as the number of milling passes increased. The viscosity of the pastes and the percent increase in volume of whipped paste decreased steadily as the particle size decreased. Overall acceptability of akara decreased as the percentage of smaller particles increased. The researchers concluded that cowpea meal or flour with a particle size distribution consisting of

60 - 70% of particles found in the mid-size (0.045 - 0.150 mm) range is ideal for making akara. Henshaw et al. (1996) measured pasting properties as an indication of functionality of cowpea flour with varying PSDs. The researchers found that flour with a minimum of 65% midsized particles (0.180 - 0.425 -mm) had the best hot paste viscosity, and would therefore perform well in foods. Barimalaa, Agoha, Oboh, and Kiin-Kabari (2005) researched the functionality of bambara groundnut (an African legume also from the *Vigna* species) flour used for making okpa (a dish similar to moinmoin). The researchers concluded that acceptable okpa could be made from bambara groundnut flours with a PSD in the medium range (0.150 - 0.425 mm).

Wet Versus Dry Milling

For several reasons, including economics and food safety, dry-milling is preferable to wet-milling for the production of cowpea flour and meal (Phillips & McWatters, 1991). Kethireddipalli, Hung, McWatters, and Phillips (2002b) compared the functional properties, namely foaming and water-holding capacity, of cowpea pastes produced from dry-milled flour and meal and traditionally prepared wet-milled paste. The water holding capacity (WHC) (g/g) of the flour paste was 1.42 compared to 3.80 for traditionally wet-milled paste. The paste prepared from cowpea meal faired better with a

WHC of 2.34 prior to blending in a kitchen blender and 3.20 once blended. The authors speculated that the wet-milling of the cowpeas allowed for facile release of cell contents, including cell wall material, by easy rupture of turgid cells. Laskowski and Lysiak (1999) saw a steady decline in the force necessary to rupture several types of legume seeds during grinding with increasing moisture content of the seeds. When wheat bran was ground, cell wall material was sheared leading to a collapse of the matrix structure that was found intact in samples subjected to a lesser degree of physical abuse during milling (Cadden, 1987). Cell walls are responsible for providing structure to the cotyledon through a matrix consisting of several components including pectin and hemicellulose (Uebersax & Ruengsakulrach, 1989). Turgor pressure, resulting when cells are fully imbibed, lessens the amount of further stress required to cause a small disruption in the cell allowing the contents of the cell to leak out still relatively intact. Flaccid cells, on the other hand, are torn and broken when subjected to stress leading to destruction of cell components (Hamann, 1983). Therefore, wet-milling is often employed with success for isolating various components found in plant cells, including fiber which consists of the cell wall matrix (Larrauri, 1999; Zheng, Sosulski, & Tyler, 1998).

Cell wall material has been shown to improve the water holding properties of foods as a result of the open spaces in the matrix structure which hold free water (Cadden, 1987). Several studies have shown that cell wall material has exceptional water holding capacities. According to Robertson and Eastwood (1981), carrot and potato fibers can hold 20 and 29 g of water per g of dry material respectively. Reichert (1981) observed that when field peas were soaked prior to maceration in a blender, the cell walls
did not break down. The cell wall material isolated from the macerated peas was able to hold 18 times its weight in water. There is variation in the water holding capacity of specific plant fibers which is influenced by physical characteristics such as particle size and preparation method (Cadden, 1987; Robertson & Eastwood, 1981). Pickardt, Dongowski, and Kunzek (2004) identified three factors that affected the hydration properties of dried carrot cell wall material and therefore its functionality in food systems: 1) composition, 2) structure/physical state of particles, and 3) rehydration conditions. The structure of the cell wall material is dependent on the processing method and the particle size.

Kethireddipalli et al. (2002a) compared the microstructure of cellular material from wet-milled cowpea paste and dry-milled flour and meal samples. Light microscopy showed noticeable differences in the samples. The traditionally wet-milled sample had few intact cells and the cell wall remnants formed networks. Rehydrated cowpea meal had coarse particles containing a large portion of intact cells and few ruptured cells; once the meal was blended, the cells were ruptured and the result was similar to that seen with the control paste (traditional wet-milled). Cowpea flour has a good deal of cell wall material, but as was seen in previous research (Sosulski et al., 1982) the small particle size resulted in the lack of a network. The cellular material isolated from the control paste was able to hold significantly more water than the material isolated from meal paste, blended meal paste and flour paste (Kethireddipalli et al., 2002a). When dry-milling is employed, a significant amount of force is exerted upon the product resulting in reduction of particle size of the cell wall component (Reichert, 1981; Sosulski et al., 1982).

Freeze Drying

Sublimation is the conversion from solid state directly to a gaseous state bypassing the liquid phase. In freeze drying, the sublimation of ice from the frozen product is accomplished through the use of controlled heat and low pressure. The use of high temperatures employed in conventional drying compromises many products with the effect most often expressed as degradation of quality. Freeze drying eliminates air during processing preventing oxidation or chemical modification of the product and the temperature maintained during the process is below ambient temperatures preventing thermal abuse of the product (Vega-Mercado, Gongora-Nieto, & Barbosa-Canovas, 2001). In addition, the solids in the product itself are not able to interact and react during the freeze drying process which minimizes changes to the product. The resulting dried product maintains many of the characteristics of the unprocessed product, has had the microbiological and deterioration reactions slowed or stopped, and is considered by most consumers as very high quality relative to other forms of processing (Ratti, 2001).

There are four conditions which must be met in order to successfully freeze dry a product. The first is that the product be frozen. Optimal freezing temperature is the product's lowest eutectic point. Freezing to a temperature above that point will result in some liquid water still being present. Freezing below the eutectic point will result in excess energy being expended in the drying process. It is necessary to impart thermal energy to the product in a controlled manner to foster thawing driving the water vapors out of the product. A high vacuum in the chamber is crucial to produce low enough pressure to ensure effective migration of water vapor from the product to the condenser surface. The condenser temperature must be low enough that the sublimed vapor

removed from the system is refrozen on the condenser surface immediately preventing the water from reentering the system (Barbosa-Canovas & Vega-Mercado, 1996). The main drawback to freeze drying is that it is expensive when compared to other food preservation methods (Ratti, 2001).

In addition to protein denaturation, traditional thermal drying of plant tissues results in changes to the physical structure of the tissue and chemical changes within the material (Lewicki & Pawlak, 2003). Microphotographs of apple cubes dried under various conditions showed that apples dried by convection maintained intact cell walls that shrank and often folded and creased without breaking open. In contrast, broken cell walls were often seen in freeze dried samples. The researchers concluded that the cell walls were broken during the freezing of the material allowing the cell wall material to leak into the voids left by freeze drying (Lewicki & Pawlak, 2003). Freezing under conditions that are not tightly regulated and controlled can lead to damage of the cells due to crystal growth. Therefore, when the cell is thawed, the liquid components can potentially leak from the cell (Senadeera, Bhandari, Young, & Wijesinghe, 2000).

Proteins not only denature at elevated temperatures, but also at lower temperatures. The basis of temperature-related denaturation is the change in free energy contributions of the various interactions and bonds that work in concert to maintain a protein's conformation with stability of a protein maximized when free energy is minimized. In some cases, the denaturation or dissociation that occurs at low temperatures is reversible (Damodaran, 1996). Chang, Kendrick, and Carpenter (1996) compared the thermal denaturation temperatures of model proteins to the freeze denaturation of those proteins and identified only a weak negative correlation, whereas a

strong positive correlation was seen between surface denaturation and freeze denaturation. The researchers concluded that freeze denaturation is closely tied to the propensity of the protein to unfold at interfaces.

Jiang and Nail (1998) researched the recovery of activity of proteins for use in pharmaceuticals after freezing and freeze drying in buffered solutions. The researchers found that as they increased the concentration of the proteins in solution, the recovery of activity also increased after both freezing and freeze drying. Concentration was concluded to be the most influential variable in the process. The researchers also found that the optimal freezing rate for recovery of activity of the proteins was an intermediate rate at -40° C. This is supported by the work of Chang et al. (1996) and Strambini and Gabellieri (1996), both of whom report more structural damage and lower recovery rates with faster freezing rates. Jiang and Nail (1998) hypothesized that an increase in supercooling during slower freezing actually increases the freezing rate upon nucleation of ice crystals. Loss of activity during freeze drying was seen to occur mainly after the residual moisture level dropped below 10%, and therefore could be prevented by ending the freeze drying prior to "over-drying" the product.

Summary

Efforts have been made to foster economic development of cowpea and cowpea derived products via the development of a readily hydratable cowpea meal or flour that could be used for making akara comparable to traditionally prepared akara. Throughout the past research, there is evidence of the importance of maintaining protein conformation, having proper particle size distribution and the presence of cell wall material after milling. These factors have all been examined; however, they have been

studied without controlling the influence of the other factors but rather by modifying the milling process. Opting for a certain mill, screen size or process over another will naturally result in variations of the milled product. Therefore, there will be differences, for example a different particle size distribution, that result from using different processes or equipment. Without controlling the influence of the other factors, it is difficult to concretely conclude that differences in the functionality of the meal are attributable solely to the particular factor being studied. Continued research is necessary to identify which of the three above mentioned factors is predominately responsible for proper functionality of cowpea paste thus resulting in akara comparable to traditionally prepared akara. In addition, although it is known that a minimum of 65% of the particles in a dry cowpea meal must fall in the medium size range (0.180 - 0.425 mm), it is unclear how important the size of the remaining 35% is. Research is needed to understand the effect of shifting the particle size range of that 35%.

References

Abbey, B. W., & Ibeh, G. O. (1988). Functional properties of raw and heat processed cowpea (*Vigna unguiculata*, Walp) flour. *Journal of Food Science*, *53* (6), 1775-1777, 1791.

Abdalla, M. H., Elkhalifa, A.O., & Eltinay, A. H. (2001). Factors affecting protein extraction from cowpea. *Journal of Food Science (Mysore)*, *38* (5), 532-533.

Ahenkora, K., Adu Dapaah, H. K., & Agyemang, A. (1998). Selected nutritional components and sensory attributes of cowpea (*Vigna unguiculata* [L.] Walp) leaves. *Plant Foods for Human Nutrition, 52*, 221-229.

Akpapunam, M. A., & Markakis, P. (1981a). Protein supplementation of cowpeas with sesame and watermelon seeds. *Journal of Food Science*, 46 (3), 960-961.

Akpapunam, M. A., & Markakis, P. (1981b). Physicochemical and nutritional aspects of cowpea flour. *Journal of Food Science*, 46 (3), 972-973.

Auffret, A, Ralet, M-C., Guillon, F., Barry, J-L., & Thibault, J-F. (1994). Effect of grinding and experimental conditions on the measurement of hydration properties of dietary fibres. *Lebensmittel-Wissenschaft und-Technologie*, *27* (2), 166-172.

Barbosa-Canovas, G. V., & Vega-Mercado, H. (1996). *Dehydration of Foods*. New York: Chapman and Hall.

Barimalaa, I. S., Agoha, G., Oboh, C. A., & Kiin-Kabari, D. B. (2005). Studies on bambara groundnut flour performance in *okpa* preparation. *Journal of the Science of Food and Agriculture*, 85, 413-417.

Boeh-Ocansey, O. (1989). Developments and challenges in Africa's food industry. *Food Technology*, 43 (5), 84-92.

Bressani, R. (1985). Nutritive value of cowpea. In S. R. Singh, K. O. Rachie, *Cowpea Research, Production and Utilization*, (pp. 353-359). Great Britain: John Wiley & Sons.

Bulgarelli, M. A, & Beuchat, L. R. (1990). Functional properties of cowpea paste as influenced by indigenous microflora. *Journal of Food Science*, 55 (1), 146-150.

Bulgarelli, M. A, Beuchat, L. R, & McWatters, K. H. (1988). Microbiological quality of cowpea paste used to prepare Nigerian akara. *Journal of Food Science*, *53* (2), 442-444, 449.

Cadden, A-M. (1987). Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. *Journal of Food Science*, *52* (6), 1595-1599, 1631.

Campbell, A. M, Penfield, M. P, & Griswold, R. M. (1979). *The Experimental Study of Food*, (2nd ed.) Boston, MA: Houghton Mifflin.

Chan, C-W., & Phillips, R. D. (1994). Amino acid composition and subunit constitution of protein fractions from cowpea (*Vigna unguiculata* L. Walp) seeds. *Journal of Agricultural and Food Chemistry*, 42, 1857-1860.

Chang, B. S, Kendrick, B. S, & Carpenter, J. F. (1996). Surface-induced denaturation of proteins during freezing and its inhibition by surfactants. *Journal of Pharmaceutical Sciences*, *85* (12), 1325-1330.

Chhinnan, M. S., McWatters, K. H., & Rao, W. N. M. (1985). Rheological characterization of grain legume pastes and effect of hydration time and water level on apparent viscosity. *Journal of Food Science*, *50* (4), 1167-1171.

Damodaran, S. (1994). Structure-function relationship of food proteins. In N. S. Hettiarachchy, G. R. Ziegler, *Protein Functionality in Food Systems*, (pp. 1-38) New York: Marcel Dekker, Inc.

Damodaran, S. (1996). Amino acids, peptides, and proteins. In O. R. Fennema, *Food Chemistry*, (3rd ed.) (pp. 321-429). New York: Marcel Dekker, Inc.

Dovlo, F. E., Williams, C. E., & Zoaka, L. (1976). *Cowpeas: Home Preparation and Use in West Africa*. IDRC-055e. Ottawa: International Development Research Centre.

Enwere, N. J., McWatters, K. H., & Phillips, R. D. (1998). Effect of processing on some properties of cowpea (*Vigna unguiculata*), seed, protein, starch, flour and akara. *International Journal of Food Science and Nutrition*, *49*, 365-373.

Enwere, N. J., & Ngoddy, P. O. (1986). Effect of heat treatment on selected functional properties of cowpea flour. *Tropical Science*, *26*, 223-232.

FAO. (2004). FAOSTAT Data: Cowpeas, Dry Production. Rome: Food and Agricultural Organization of the United Nations. Retrieved May 23, 2005 from the World Wide Web http://faostat.fao.org/faostat/collections?subset=agriculture.

Friedman, H. H., Whitney, J. E., & Surmacka Szczesniak, A. (1963). The texturometer— A new instrument for objective texture measurement. *Journal of Food Science*, *29*, 390-396.

Giami, S. Y. (1993). Effect of processing on the proximate composition and functional properties of cowpea (*Vigna unguiculata*) flour. *Food Chemistry*, 47, 153-158.

Giese, J. (1994). Proteins as ingredients: types, functions, applications. *Food Technology*, 48 (10), 50-60.

Hamann, D. D. (1983). Structural failure in solid foods. In M. Peleg, E. B Bagle, *Physical Properties of Foods*, (p. 379). Westport, Connecticut: AVI Publishing Company, Inc.

Han, J-Y., & Khan, K. (1990a). Physicochemical studies of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 384-390.

Han, J-Y., & Khan, K. (1990b). Functional properties of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 390-394.

Hanselmann, W., & Windhab, E. (1999). Flow characteristics and modelling of foam generation in a continuous rotor/stator mixer. *Journal of Food Engineering*, *38*, 393-405.

Henshaw, F. O., & Lawal, S. A. (1993). Effects of processing method on the functional properties of cowpea flour. *Tropical Science*, *33*, 377-385.

Henshaw, F. O., McWatters, K. H., Oguntunde, A. O., & Phillips, R. D. (1996). Pasting properties of cowpea flour: effects of soaking and decortication method. *Journal of Agricultural and Food Chemistry*, 44 (7), 1864-1870.

Holt, S. D., Resurreccion, A. V. A., & McWatters, K. H. (1992a). Formulation, evaluation and optimization of tortillas containing wheat, cowpea and peanut flours using mixture response surface methodology. *Journal of Food Science*, *57* (1), 121-127.

Holt, S. D., Resurreccion, A. V. A., & McWatters, K. H. (1992b). Validation of predicted baking performance of muffins containing mixtures of wheat, cowpea, peanut, sorghum, and cassava fours. *Journal of Food Science*, *57* (2), 470-474.

Hung, Y-C., & McWatters, K. H. (1990). Effect of holding time on the functionality of cowpea paste and quality of akara. *Journal of Food Science*, *55* (2), 558-559. Hung, Y-C., McWatters, K. H, & Chinnan, M. S. (1988a). A microscopic method to quantify whippability. *Journal of Food Science*, *53* (5), 1566-1569.

Hung, Y-C., Chinnan, M. S., & McWatters, K. H. (1988b). Effect of pre-decortication drying treatment on the textural quality of cowpea products: seeds and akara. *Journal of Food Science*, *53* (6), 1778-1781.

Hung, Y-C., McWatters, K. H., Phillips, R. D., Beuchat, L. R., & Chinnan, M. S. (1995). Physicochemical, microbiological, and akara-making properties of hard-to-cook cowpeas. *Journal of Agricultural and Food Chemistry*, *43* (4), 989-992.

Jiang, S., & Nail, S. L. (1998). Effect of process conditions on recovery of protein activity after freezing and freeze-drying. *European Journal of Pharmaceutics and Biopharmaceutics*, 45, 249-257.

Kaur, M., & Singh, N. (2005). Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arientinam* L.) cultivars. *Food Chemistry*, *91*, 403-411.

Kerr, W. L., Ward, C. D. W., McWatters, K. H., & Resurreccion, A. V. A. (2000). Effect of milling and particle size on functionality and physicochemical properties of cowpea flour. *Cereal Chemistry*, 77 (2), 213-219.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002a). Evaluating the role of cell wall material and soluble protein in the functionality of cowpea (*Vigna unguiculata*) pastes. *Journal of Food Science*, 67 (1), 53-59.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002b). Effect of milling method (wet and dry) on the functional properties of cowpea (*Vigna unguiculata*) pastes and end product (akara) quality. *Journal of Food Science*, 67 (1), 48-52.

Kinsella, J. E. (1984). Functional properties of food proteins: thermal modification involving denaturation and gelation. In J. V. McLoughlin, B. M. McKenna, *Research in Food Science and Nutrition, Volume 5, Food Science and Technology: Present Status and Future Direction*, (pp. 226-246) Dublin, Ireland: Boole Press. Larrauri, J. A. (1999). New approaches in preparation of high dietary fibre powders from fruit by-products. *Trends in Food Science and Technology*, *10*, 3-8.

Laskowski, J., & Lysiak, G. (1999). Use of compression behaviour of legume seeds in view of impact grinding prediction. *Powder Technology*, *105*, 83-88.

Lewicki, P. P., & Pawlak, G. (2003). Effect of drying on microstructure of plant tissue. *Drying Technology*, *21* (4), 657-683.

Liu, K., Phillips, R. D., Hung, Y-C., Shewfelt, R. L., & McWatters, K. H. (1992). Hard-to-cook defect in cowpeas: storage-induced and treatment-induced development. *Journal of Food Science*, *57* (5), 1155-1160.

Marsili, R. (1993). Protein Power: Functionality and versatility. Food Product Design. Retrieved May 23, 2005 from the World Wide Web October 28, 2004. www.foodproductdesign.com/archive/1993/0993ap2.html

McWatters, K. H. (1983). Compositional, physical and sensory characteristics of *akara* processed from cowpea paste and Nigerian cowpea flour. *Cereal Chemistry*, *60* (5), 333-336.

McWatters, K. H. (1985). Functionality of cowpea meal and flour in selected foods. In S. R. Singh, K. O. Rachie, *Cowpea Research, Production and Utilization*, (pp. 361-366). Great Britain: John Wiley & Sons.

McWatters, K. H. (1986). Use of peanut and cowpea flours in selected fried and baked foods. In R. L. Ory, *Plant Proteins, Applications, Biological Effects, and Chemistry*, (pp. 8-18). Washington, DC: American Chemical Society.

McWatters, K. H., & Brantley, B. B. (1982). Characteristics of akara prepared from cowpea paste and meal. *Food Technology*, *36*, 66-68.

McWatters, K. H., & Chhinnan, M. S. (1985). Effect of hydration of cowpea meal on physical and sensory attributes of a traditional west African food. *Journal of Food Science*, *50* (2), 444-446, 453.

McWatters, K. H., Chinnan, M. S., Hung, Y-C., & Branch, A. L. (1988). Effect of predecortication drying temperature on cowpea paste characteristics and functionality in preparation of akara. *Cereal Chemistry*, 65 (1), 23-27.

McWatters, K. H., Chinnan, M. S., Worthington, R. D., & Beuchat, L. R. (1987). Influence of storage conditions on quality of cowpea seeds and products processed from stored seeds. *Journal of Food Processing and Preservation*, *11*, 63-76.

McWatters, K. H., & Flora, F. (1980). A deep-fried product from southern peas. *Food Technology*, *34* (11), 71-74.

Mensa-Wilmot, Y., Phillips, R. D., & Hargrove, J. L. (2001). Protein quality evaluation of cowpea-based extrusion cooked cereal/legume weaning mixtures. *Nutrition Research*, *21*, 849-857.

Mensa-Wilmot, Y., Phillips, R. D., & Sefa-Dedeh, S. (2001). Acceptability of extrusion ooked cereal/legume weaning food supplements to Ghanaian mothers. International *Journal of Food Science and Nutrition*, *52*, 83-90.

Mongeau, R., & Brassard, R. (1982). Insoluble dietary fiber from breakfast cereals and brans: bile salt binding and water-holding capacity in relation to particle size. *Cereal Chemistry*, *59* (5), 413-417.

Mortimore, M. J., Singh, B. B., Harris, F., & Blade, S. F. (1997). Cowpea in traditional cropping systems. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, L. E. N. Jackai, *Advances in Cowpea Research*, (pp. 99-113). Ibadan, Nigeria: Co-publication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Sciences.

Nagmani, B., & Prakash, J. (1997). Functional properties of thermally treated legume flours. *International Journal of Food Science and Nutrition*, 48, 205-214.

Narayana, K., & Narasinga Rao, M. S. (1982). Functional properties of raw and heat processed winged bean flour. *Journal of Food Science*, *47*, 1534-1538.

Ngoddy, P. O., Enwere, N. J., & Onuorah, V. I. (1986). Cowpea flour performance in akara and moin-moin preparations. *Tropical Science*, *26*, 101-119.

Nielsen, S. S., Ohler, T. A., & Mitchell, C. A. (1997). Cowpea leaves for human consumption: production, utilization, and nutrient composition. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, L. E. N. Jackai, *Advances in Cowpea Research*, (pp. 326-332). Ibadan, Nigeria: Co-publication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Sciences.

Nnanna, I. A., & Phillips, R. D. (1988). Changes in oligosaccharide content, enzyme activities and dry matter during controlled germination of cowpeas (*Vigna unguiculata*). *Journal of Food Science*, *53* (6), 1782-1786.

Nnanyelugo, D. O., Ngoddy, P. O., Okeke, E. C., & Ngwu, E. K. (1997). Impact of a cowpea research project in Nigeria, using the rapid rural appraisal technique. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, L. E. N. Jackai, *Advances in Cowpea Research*, (pp. 333-340). Ibadan, Nigeria: Co-publication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Sciences.

Onayemi, O., & Potter, N. (1976). Cowpea powders dried with methionine: preparation, storage stability, organoleptic properties, nutritional quality. *Journal of Food Science*, *41* (1), 48-53.

Patterson, S. P., McWatters, K. H., Hung, Y-C., Chinnan, M. S., & Phillips, R. D. 2002. Physico-chemical properties and consumer acceptability of akara (fried paste) made from three cowpea cultivars. *Food Research International*, *35*, 691-696.

Phillips, R. D. (1993). Starchy legumes in human nutrition, health and culture. Plant *Food for Human Nutrition, 44*, 195-211.

Phillips, R. D., Chinnan, M. S., Branch, A. L., Miller, J., & McWatters, K. H. (1988). Effects of pretreatment on functional and nutritional properties of cowpea meal. *Journal of Food Science*, *53* (3), 805-809.

Phillips, R. D., & McWatters, K. H. (1991). Contribution of cowpeas to nutrition and health. *Food Technology*, 45 (9), 127-130.

Phillips, R. D., McWatters, K. H., Chinnan, M. S., Hung, Y-C., Beuchat, L. R., Sefa-Dedeh, S., Sakyi-Dawson, E., Ngoddy, P., Nnanyelugo, D., Enwere, J., Komey, N. S., Liu, K., Mensa-Wilmot, Y., Nnanna, I. A., Okeke, C., Prinyawiwatkul, W., & Saalia, F. K. (2003). Utilization of cowpeas for human food. *Field Crops Research*, *82*, 193-213.

Pickardt, C., Dongowski, G., & Kunzek, H. (2004). The influence of mechanical and enzymatic disintegration of carrots on the structure and properties of cell wall materials. *European Food Research and Technology*, *219* (3), 229-239.

Plahar, W. A., Annan, N. T., & Nti, C. A. (1997). Cultivar and processing effects on the pasting characteristics, tannin content and protein quality and digestibility of cowpea (*Vigna unguiculata*). *Plant Foods for Human Nutrition*, *51*, 343-356.

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L. R., & Phillips, R. D. (1994). Physical properties of cowpea paste and akara as affected by supplementation with peanut flour. *Journal of Agricultural and Food Chemistry*, *42* (8), 1750-1756.

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L. R., & Phillips, R. D. (1996). Cowpea flour: A potential ingredient in food products. *Critical Reviews in Food Science and Nutrition*, *36* (5), 413-436.

Rachie, K. O. (1985). Introduction. In S. R. Singh, K. O. Rachie, *Cowpea Research*, *Production and Utilization*, (pp. xxi-xxviii). Great Britain: John Wiley & Sons.

Rader, J. I., Weaver, C. M., & Angyal, G. (2000). Total folate in enriched cereal-grain products in the United States following fortification. *Food Chemistry*, 70 (3), 275-289.

Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., & Tharanathan, R. N. (2004). Dietary fiber from coconut residue: effects of different treatments and particle size on the hydration properties. *European Food Research and Technology*, *218* (6), 563-567.

Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. *Journal of Food Engineering*, 49, 311-319.

Reichert, R. D. (1981). Quantitative isolation and estimation of cell wall material from dehulled pea (*Pisum sativum*) flours and concentrates. *Cereal Chemistry*, 58 (4), 266-270.

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J-F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *Lebensmittel-Wissenschaft und-Technologie*, *33* (2), 72-79.

Robertson, J. A., & Eastwood, M. A. (1981). An investigation of the experimental conditions which could affect water-holding capacity of dietary fiber. *Journal of the Science of Food and Agriculture*, *32*, 819-825.

Sefa-Dedeh, S., & Stanley, D. W. (1979). The relationship of microstructure of cowpeas to water absorption and dehulling properties. Cereal Chemistry, 56 (4), 379-386.

Senadeera, W., Bhandari, B., Young, G., & Wijesinghe, B. (2000). Physical property changes of fruits and vegetables during hot air drying. In A. S. Mujumdar, *Drying Technology in Agriculture and Food Sciences, (pp. 149-162)*. Enfiled, New Hampshire, USA: Science Publishers, Inc.

Sikorski, Z E. (1997). Proteins. In Z. E. Sikorski, *Chemical and Functional Properties of Food Components*, (pp. 119-160). Lancaster, Pennsylvania: Technomic Publishing Company, Inc.

Singh, A. (2003). Enhancing the physical and functional properties of cowpea paste used in akara production through modification of milling and paste preparation methods [MSci thesis]. Univ of Georgia, Athens, Ga.

Singh, A., Hung, Y-C., Phillips, R. D., Chinnan, M. S., & McWatters, K. H. (2004). Particle-size distribution of cowpea flours affects quality of akara (fried cowpea paste). *Journal of Food Science*, 69 (7), 243-249.

Singh B. B., Ajeigbe, H. A., Tarawali, S. A., Fernandez-Rivera, S., & Abubakar, M. (2003). Improving the production and utilization of cowpea food as fodder. *Field Crops Research*, *84*, 169-177.

Sosulski, F. W., Elkowicz, L., & Reichert, R. D. (1982). Oligosaccharides in eleven legumes and their air-classified protein and starch fractions. *Journal of Food Science*, *47*, 498-502.

Strambini, G. B., & Gabellieri, E. (1996). Proteins in frozen solutions: evidence of iceinduced partial unfolding. *Biophysical Journal*, *70*, 971-976. Tarawali, S. A., Singh, B. B., Peters, M., & Blade, S. F. (1997). Cowpea haulms as fodder. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, L. E. N. Jackai, *Advances in Cowpea Research*, (pp. 313-325). Ibadan, Nigeria: Copublication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Sciences.

Thomas Jefferson Agricultural Institute. (2004). Crop Production Guides: Cowpea, A Versatile Legume for Hot, Dry Conditions. United States: Thomas Jefferson Agricultural Institute. Retrieved October 26, 2004 from World Wide Web http://www.jeffersoninstitute.org/pubs/cowpea.shtml.

Tuan, Y-H., & Phillips, R. D. (1992). Nutritional quality of hard-to-cook processed cowpea. *Journal of Food Science*, *57* (6), 1371-1374.

Uebersax, M. A., & Ruengsakulrach, S. (1989). Structural and compositional changes during processing of dry beans (*Phaseolus vulgaris*). In J. J. Jen, *Quality factors of fruits and vegetables*, (pp. 111-124). Washington D.C.: American Chemical Society.

Uwaegbute, A. C., Iroegbu, C. U., & Eke, O. (2000). Chemical and sensory evaluation of germinated cowpeas (*Vigna unguiculata*) and their products. *Food Chemistry*, *68*, 141-146.

Uzogara, S. G., & Ofuya, Z. M. (1992). Processing and utilization of cowpeas in developing countries: a review. *Journal of Food Processing and Preservation*, *16*, 105-147.

Vega – Mercado, H., Gongora-Nieto, M. M., & Barbosa-Canovas, G. V. (2001). Advances in dehydration of foods. *Journal of Food Engineering*, 49, 271-289.

Voutilainen, S., Virtanen, J. K., Rissanen, T. H., Alfthan, G., Laukkanen, J., Nyyssonen, K., Mursu, J., Valkonen, V-P., Tuomainen, T-P., Kaplan, G. A., & Salonen, J. (2004). Serum folate and homocysteine and the incidence of acute coronary events: the Kupio Ischaemic Heart Disease Risk Factor Study. American Journal of Clinical Nutrition, 80, 317-323.

Ward, C. D. W., Resurreccion, A. V. A., & McWatters, K. H. (1998). Comparison of acceptance of snack chips containing cornmeal, wheat flour and cowpea meal by U.S. and West African consumers. *Food Quality and Preference*, *9* (5), 327-332.

Zheng, G. H., Sosulski, F. W., & Tyler, R. T. (1998). Wet-milling and functional properties of starch and protein isolated from buckwheat groats. *Food Research International*, *30* (7), 493-502.

SECTION II

PRELIMINARY WORK

Past research has shown that in order to produce cowpea meal or flour acceptable for use in preparing akara, there are three key factors: 1) cowpea proteins must maintain their natural conformation, 2) particle size distribution of meal or flour must consist of at least 65% particles that fall in the medium size range, i.e. between 0.180 and 0.425 mm, and 3) chunks of cell wall matrix must be present after processing (Abbey & Ibeh, 1988; Enwere, McWatters, & Phillips 1998; Henshaw, McWatters, Oguntunde, & Phillips, 1996; Kethireddipalli, Hung, McWatters, & Phillips, 2002a and b; McWatters, 1983; McWatters, Chinnan, Hung, & Branch, 1988; Ngoddy, Enwere, & Onuorah, 1986; Phillips, Chinnan, branch, Miller & McWatters, 1988; Singh, Hung, Phillips, Chinnan & McWatters, 2004). However, the research has tended to focus on these factors as individual components without controlling for the other factors in the system. It was our intention to process cowpea meals using methods that allowed for the isolation of each of the three factors. Singh et al. (2004) produced a dry milled meal using a hammer mill with a 2.54 mm screen that was used to produce acceptable akara; however, there is some question about the potential for thermal abuse during the milling process when using a hammer mill. For this study, in addition to the 2.54 mm hammer milled meal, cowpea meal and flour were processed using freeze drying technology which allowed for wet milling coupled with non-thermal drying. Pastes made from the freeze dried meal and flour samples were then evaluated along with traditional wet milled paste and dry milled cowpea meal paste.

Different methods for processing the peas prior to and post freeze drying were evaluated to determine the method that worked best to produce meal or flour that could be used for making akara. Grinding the soaked peas using a plate mill (Model 4E

Grinding Mill, The Straub Co., Hatboro, PA) was reasoned to be mechanically most similar to the hand grinding with a mortar and pestle employed in traditional wet milling. Therefore, a meal was processed by grinding fully hydrated peas (soaked overnight) in the plate mill with the plates tightened to the lowest clearance (approximately 2.75 mm). The paste was then freeze dried in a Genesis SQ25 Super ES freeze drier (The VirTis Co., Gardiner, NY) and ground a second time in the plate mill (tightened to approximately 2.75 mm clearance). However, the plate mill was not able to grind the soaked peas into a smooth enough paste; the resulting meal had very large particles and required extensive further processing (i.e. chopping in a food processor prior to blending) to produce a paste that could be used for making akara. Next, a food grinder (Hobart Commercial Food Chopper model 4812, Troy, OH) was employed to grind the soaked peas. In order to prevent the grinder from gumming up, a succession of plates was used; the peas were first ground through a plate with 4.763 mm (3/16 in) diameter holes then a plate with 3.175 mm (2/16 in) diameter holes. The resulting paste was freeze dried and then ground in the plate mill (clearance approximately 2.75 mm); this process produced a meal with manageable particle size that could easily be used for akara preparation.

In addition to the plate mill, the dried paste was also milled in a wing mill (Super Wing Mill, DM-200, Sanwa Engineering Co., LTD, Thailand) which produced very fine flour. The paste resulting from rehydrating the fine flour had a very low viscosity making the paste impossible to handle even though it was rehydrated to only 58% moisture compared to 65% for the other samples being examined. In addition, the percent change in specific gravity was only 11.2% meaning the paste did not adequately foam and could not be used to produce akara. The initial wet milling of the paste was

determined to be inconsequential when the particle size reduction was so great. In addition, it is known that the wing mill produces heat during the milling process meaning the flour was subjected to a degree of thermal abuse.

Initial quality measurements of freeze dried meal paste indicated the meal was not an acceptable starting material as the percent change in the specific gravity was low (19.7%) and the akara made was dense and not well formed (textural analysis was not performed as the akara was misshapen). It was concluded that wet milling alone was not sufficient to determine the functionality of cowpea meal; it was therefore decided to fractionate the meal via sieving and recombine the fractions in defined particle size distributions. One hundred grams of meal was sieved by mechanical shaking (RX-86, W.S. Tyler, Mentor, OH) for 10 minutes using a series of sieves (#40, 100, 400) and a collection pan (USA Standard Testing Sieve, ASTME II Specification, Fisher Scientific, Pittsburgh, PA). Upon sieving, it was observed that the majority of the particles in the freeze dried meal were above the medium size range (collected from the #40 sieve). As mentioned above, other researchers have reported the necessity of a minimum of 65% medium size range particles; consequently, it was decided to conduct a study evaluating wet milled and dry milled cowpea meals with particle size blends containing a minimum of 65% medium particles with the remaining 35% made up of various combinations of large (>0.425 mm) and fine (0.045 - 0.180 mm) particles, the results of which are reported in Section III of this thesis.

References

Abbey, B. W., & Ibeh, G. O. (1988). Functional properties of raw and heat processed cowpea (*Vigna unguiculata*, walp) flour. *Journal of Food Science*, *53* (6), 1775-1777, 1791.

Enwere, N. J., McWatters, K. H., & Phillips, R. D. (1998). Effect of processing on some properties of cowpea (*Vigna unguiculata*), seed, protein, starch, flour and akara. *International Journal of Food Science and Nutrition*, *49*, 365-373.

Henshaw, F. O., McWatters, K. H., Oguntunde, A. O., & Phillips, R. D. (1996). Pasting properties of cowpea flour: effects of soaking and decortication method. *Journal of Agricultural and Food Chemistry*, 44 (7), 1864-1870.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002a). Effect of milling method (wet and dry) on the functional properties of cowpea (*Vigna unguiculata*) pastes and end product (akara) quality. *Journal of Food Science*, 67 (1), 48-52.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002b). Evaluating the role of cell wall material and soluble protein in the functionality of cowpea (*Vigna unguiculata*) pastes. *Journal of Food Science*, 67 (1), 53-59.

McWatters, K. H. (1983). Compositional, physical and sensory characteristics of *akara* processed from cowpea paste and Nigerian cowpea flour. *Cereal Chemistry*, *60* (5), 333-336.

McWatters, K. H., Chinnan, M. S., Hung, Y-C., & Branch, A. L. (1988). Effect of predecortication drying temperature on cowpea paste characteristics and functionality in preparation of akara. *Cereal Chemistry*, 65 (1), 23-27.

Ngoddy, P. O., Enwere, N. J., & Onuorah, V. I. (1986). Cowpea flour performance in akara and moin-moin preparations. *Tropical Science*, *26*, 101-119.

Phillips, R. D., Chinnan, M. S., Branch, A. L., Miller, J., & McWatters, K. H. (1988). Effects of pretreatment on functional and nutritional properties of cowpea meal. *Journal of Food Science*, *53* (3), 805-809.

Singh, A., Hung, Y-C., Phillips, R. D., Chinnan, M. S., & McWatters, K. H. (2004). Particle-size distribution of cowpea flours affects quality of akara (fried cowpea paste). *Journal of Food Science*, *69* (7), 243-249.

SECTION III

EFFECT OF PROCESSING VARIABLES OF COWPEA (Vigna unguiculata) MEAL ON FUNCTIONAL PROPERTIES OF COWPEA PASTE AND QUALITY OF AKARA (fried cowpea paste)¹

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Abstract

The importance of particle size distribution in conjunction with milling method (dry milled hammer milled meal [HM] or wet milled freeze dried meal [FD]) on the functionality of cowpea paste and textural characteristics of akara was investigated. All meal samples contained a minimum of 65% by weight medium sized particles and different combinations of large and fine particles to compose the balance. With the exception of the pastes made from meal consisting of 35% fine particles, all pastes had good foaming ability and handling characteristics. However, akara made from the HM and FD blends with 35% large particles had hardness values not significantly different from traditionally prepared (wet milled) akara (5.317N, 4.048N, and 5.341N respectively), indicating the meal blends had the potential to produce akara acceptable to consumers.

Key words: cowpea, *Vigna unguiculata*, akara, cowpea meal, particle size distribution, functional properties, texture

Introduction

Vigna unguiculata, a legume commonly known as the cowpea, is an important dietary staple in many developing nations because of its high nutritional value, low cost and availability (Boeh-Ocansey, 1989; Prinyawiwatkul, McWatters, Beuchat & Phillips, 1996; Uzogara & Ofuya, 1992). In tropical and subtropical regions where the cowpea is a crucial component in the diet (Akpapunam & Markakis, 1981), the legume is included in casseroles, stews, soups and salads, is processed into various steamed or fried products, is roasted for snacking, and is often combined with other staple products of a given area to provide high quality protein to the diet (Dovlo, Williams & Zoaka, 1976; Uzogara & Ofuya, 1992; Nnanyelugo, Ngoddy, Okeke, & Ngwu, 1997). Cowpeas are approximately 24% protein with an amino acid content complementary to that found in cereals, 60% carbohydrates, contain numerous vitamins and minerals and are a good source of dietary fiber (Phillips & McWatters, 1991; Bressani, 1985; Phillips, 1993).

Akara is a traditional African product prepared by deep frying cowpea paste that has been whipped and seasoned with salt, chopped onions and either hot or bell peppers. The outer crust of akara is crisp and the interior is spongy and bread-like. Akara is considered to be the most commonly consumed cowpea derived food in West Africa (Dovlo et al., 1976). It is often eaten as a snack food throughout the day and for breakfast (McWatters, Hung, Hung, & Chinnan, 2001; Uzogara & Ofuya, 1992). Akara is made by individuals in the home and sold fully prepared by vendors in marketplaces (Phillips & McWatters, 1991). The traditional process for making akara is very time consuming and labor intensive and requires the cowpeas be soaked, manually decorticated and wet milled. Microbial spoilage necessitates that the paste be used within

several hours or be discarded, meaning paste can not be prepared ahead of time and stored (Bulgarelli, Beuchat, & McWatters, 1988).

To simplify akara preparation, easy-to-use readily-hydratable cowpea meals and flours have been developed. Meals and flours currently available on the commercial market meet the requirement of being convenient, but do not produce end products on par with freshly prepared products. Akara prepared from commercially available meals and flours lacked the typical and desired fresh cowpea flavor and had a dense, dry texture disliked by consumers (Dovlo et al., 1976; McWatters, 1983). An amalgam of growing, storage, and processing conditions, as well as genetic variety, influence the functional properties of legume components (Kaur & Singh, 2005). The functional properties of paste made from hydrated meal or flour determine its acceptance as a starting material for akara (Phillips & McWatters, 1991).

Past research has been conducted with the aim of improving the functionality of cowpea meal and flour. Based on data from these past studies, it can be concluded that there are three keys to making acceptable akara from a processed meal or flour: 1) cowpea proteins must maintain their natural conformation, 2) particle size distribution of meal or flour must consist of at least 65% particles that fall in the medium size range, i.e. between 0.180 mm and 0.425, and 3) chunks of cell wall matrix must be present after processing (Abbey & Ibeh, 1988; Enwere, McWatters, & Phillips, 1998; Henshaw, McWatters, Oguntunde, & Phillips, 1996; Kethireddipalli, Hung, McWatters, & Phillips, 2002a and b; McWatters, 1983; Ngoddy, Enwere, & Onuorah, 1986; Phillips, Chinnan, Branch, Miller, & McWatters, 1988; Singh, Hung, Phillips, Chinnan, & McWatters,

2004). Although each of these factors is known to be core and it is assumed they are confounding, the degree of importance of each factor is not well understood.

The proteins found in cowpeas serve many purposes in paste and subsequent akara preparation. Foaming ability, the decisive functional property of cowpea paste in akara preparation, is dependent on protein quality as proteins act as surfactants by quickly absorbing water at the water-air interface and undergoing a rapid rearrangement to form a viscoelastic film around the air bubbles during the incorporation of air (Damodaran, 1994). However, proteins are somewhat delicate, and the increased temperatures endured during processing may alter conformation thus compromising functionality, which is dependent on physical structure and physico-chemical characteristics (Damodaran, 1996; Giese, 1994; Marsili, 1993). A protein's functionality is dependent not only on conformation, but also on solubility. Phillips et al. (1988) demonstrated that changes seen in the specific gravity of cowpea paste paralleled changes seen in the solubility of cowpea proteins. Solubility of cowpea and other legume proteins has repeatedly been shown by researchers to be negatively affected by heat processing (Abbey & Ibeh, 1988; Enwere & Ngoddy, 1986; Henshaw & Lawal, 1993; Giami, 1993; Phillips et al., 1988; Nagmani & Prakash, 1997). Researchers demonstrated that apparent viscosity of cowpea pastes made from processed meals increased with increasing drying temperatures (McWatters, Chinnan, Hung, & Branch, 1988).

In addition to the foaming of cowpea paste, the hydration characteristics of the starting material and resulting flow characteristics of the paste influence the final appearance and texture, and hence the acceptability, of akara (McWatters & Brantley, 1982). Starting material with a low level of hydration resulted in a dry dense product

with a tough outer crust (McWatters, 1983). Several researchers have observed decreases in functionality of plant fibers (i.e. water holding capacity) with decreasing particle size upon milling of plant material, and attributed this to the alteration of fiber structure and loss of the cell wall matrix due to shearing of the plant cells (Auffret, Ralet, Guillon, Barry, & Thibault, 1994; Cadden, 1987; Han & Kahn, 1990a and b; Mongeau & Brassard, 1982). Different milling techniques employing various mill screen sizes influence the particle size distribution resulting in a potentially broad particle size range depending on the equipment and processing method used to mill the meal or flour.

Although dry milling is preferable to wet milling because of economic and food safety issues (Phillips & McWatters, 1991), the question of how to produce akara that matches the quality of traditionally wet milled product using a dry milled starting material has challenged researchers. Microscopic examination of hydrated cellular material from wet milled cowpea paste and pastes produced from dry-milled cowpea meal and flour showed a difference in the amount of cell wall material (CWM) present and the condition of the CWM (Kethireddipalli et al., 2002b). The researchers observed a significant amount of cell wall matrix forming networks in the WTM material, whereas cellular material from meal paste consisted of many intact cells. Finely milled flour also contained a significant amount of CWM; however, it lacked a network because of fine fragmentation during milling. The authors speculated that the wet-milling of the cowpeas allowed for facile release of cell contents, including cell wall material, by easy rupture of turgid cells. The authors attributed the improved hydration and foaming characteristics and the superior texture of the akara made from the wet milled paste to the presence of the light and fluffy cell wall matrix.

In order to determine the importance of the quality keys mentioned above, it was necessary to employ processing methods that allowed for control of each. Therefore, it was decided to use a wet milling process to produce a cowpea paste which was then freeze dried and ground into a meal to be compared with a dry milled meal and traditionally prepared cowpea paste. Hammer milling dry undecorticated cowpeas has been shown to produce an acceptable meal when a 2.54 mm screen was used (Singh et al., 2004). Initial quality tests indicated that control of thermal abuse and milling method alone did not ensure control of functionality and thus control of akara quality. Therefore, each of these two meals was fractionated via sieving with the particles recombined in order to control for particle size distribution.

The purpose of this study was to identify the extent to which manipulation of particle size distribution (PSD) of cowpea meal influences functionality of cowpea paste, and hence quality of akara, made from processed dry meal.

Materials and Methods

Processing of Cowpea Meals

California Cream cowpeas, *Vigna unguiculata*, breeding line UCR 97-15-33, (an all cream cultivar) were obtained from Inland Empire Foods, Riverside, California. Upon receipt, seeds were placed in a plastic container with lid and stored at 4° C until used. Moisture content of intact seeds was determined to be 9.68% by calculating weight difference after drying in vacuum oven (Fisher Scientific Isotemp Vacuum Oven, Model 285A) for 24 hours at 70° C 25mm Hg (modified AOAC method 925.09, AOAC, 1995).

Freeze Dried Meal

Batches of approximately 0.8 kg (1.75 lb) of cowpeas were spread in a deep tray, covered with tap water, and soaked overnight (approximately 18 hours). The seeds were drained and then ground undecorticated in a Hobart Commercial Food Chopper (model 4812, Troy, OH) using a plate with 4.763 mm (3/16 in) diameter holes. The cowpea paste was immediately ground a second time using a plate with 3.175 mm (2/16 in) diameter holes. The paste was spread in plastic pans lined with wax paper, covered, and placed in a -18° C freezer until frozen (approximately 24 hours). The frozen cowpea paste was freeze dried using a Genesis SQ25 Super ES freeze drier (The VirTis Co., Gardiner, NY) until dry. Dryness was determined to be when the internal temperature of the paste equilibrated with the temperature of the heat source (the shelves holding the trays). The dried cowpea paste was then ground using a plate mill (Model 4E Grinding Mill, The Straub Co., Hatboro, PA) with the plates tightened to the lowest clearance (approximately 2.75 mm). Final moisture content of the freeze dried cowpea meal (FD) was determined to be 4.99%.

Hammer Milled Meal

Cowpeas were dry milled in a hammer mill (Champion model, 6 x 14, Champion Products Inc., Eden Prairie, MN) using a 2.54 mm screen. Final moisture content of the hammer milled cowpea meal (HM) was determined to be 10.68%.

Meal Fractionation and Particle Size Blends

To fractionate the meals via particle size, 100 g of meal was sieved by mechanical shaking (RX-86, W.S. Tyler, Mentor, OH) using a series of sieves (#40, 100, 400) and a collection pan (USA Standard Testing Sieve, ASTME II Specification, Fisher Scientific,

Pittsburgh, PA) for 10 min. In order to obtain the further separation for the large portion of freeze dried meal, the meal collected from the #40 sieve was further fractionated using sieves #18, 20, 30 and a collection pan following the same procedure.

Past research has clearly indicated a minimum of 65% medium sized particles (0.180 - 0.425 mm) is necessary for proper functionality (Henshaw et al., 1996; Ngoddy et al., 1986). Therefore, each blend in this study had a minimum of 65% medium particles. The remaining 35% consisted of various combinations of large (>0.425 mm) and fine (0.045 - 0.180 mm) particles designed to enable determination of the influence of each particle size fraction on functionality. The fractions were combined by weight for the final PSDs listed in Table 2.1. Meal was vacuum sealed in high density barrier bags and stored at 4° C until needed.

The hammer milled sample of the original blend 5 (5A) (4L:0F) performed much better than the freeze dried sample of the same blend. Visual observation clearly indicated that the main difference between the hammer milled and freeze dried samples was the large fraction PSD. Therefore, the PSD of the hammer milled large fraction was determined and replicated to make the freeze dried 5B (4L:0F) blend. Particle size for the large particles in blend 5B had 3 subfractions of equal proportion; these subfractions were: 0.850 - 1.00 mm, 0.600 - 0.850 mm, 0.425 - 0.600 mm.

In order to facilitate the reporting of this study, the blends are from this point forward referred to by their IDs (processing method followed by blend number, i.e. HM1) followed by the ratio of large (L) to fine (F) particles in the remaining 35% of the blend (i.e. 2L:2F).

Preparation of Cowpea Pastes

Traditional wet milled paste

Traditionally wet milled cowpea paste (WTM) was used as the control for all experiments. The paste was made by the method described by McWatters, Hung, Hung, and Chinnan (2001). Dry seeds were weighed, soaked in tap water for 3 hours, and then drained in a colander for 5 min. The drained cowpeas were weighed, placed in a mini food chopper (Sunbeam Oskar, Model 14081, Oak Brook, IL) and chopped for 90 seconds for 30 second intervals with scraping and stirring in between. The chopped cowpeas were then transferred to a blender (Osterizer, model no. 6641, Sunbeam Products, Inc., Boca Raton, FL) and a necessary amount of water was added to bring the moisture content of the paste to 65%. The following equation, modified to account for the use of cream variety cowpeas that did not require decortication, was used to calculate the amount of water added:

$$W_a = W_1(100 - M_i/100 - M_f) - W_s$$

where, W_a is the weight of water needed to bring moisture content of paste to the target moisture content

- W₁ is the initial weight of dry seeds
- M₁ is the moisture content of dry seeds
- M_f is the target moisture content of paste
- W_s is the weight of seeds after soaking 3 hours and draining 5 min

The paste was blended on the "Low" speed "Blend" setting for 90 seconds for 30 second intervals with scraping and stirring in between. The paste was then transferred to a bowl and whipped using a hand mixer (model no. 2486, Sunbeam Products, Inc., Hattiesburg, MS) for 90 seconds on the highest speed setting (#6).

Meal pastes

One hundred grams of meal was weighed and placed in a bowl. Water necessary to bring the moisture content of the paste up to 65% was added slowly with constant gentle stirring to ensure uniform wetting, and the meal was hydrated for 15 min. The hydrated paste was transferred to the Osterizer blender and blended on the "Low" speed "Blend" setting for 90 seconds for 30 second intervals with scraping and stirring in between. The paste was then transferred to a bowl and whipped using the Sunbeam hand mixer for 90 seconds on the highest speed setting (#6).

Preparation of Akara

Akara was made by the procedure described by McWatters et al. (2001). The whipped paste was scooped with a stainless steel scoop (#40, approximately 30 ml [7/8 oz.] capacity, The ABC Collection, Japan) into hot (preheated to 193° C) peanut oil in a counter-top deep-fat fryer (Presto Kitchen Kettle Electric Multi Cooker, model no. 06000-04, National Presto Industries, Eau Claire, WI). Akara made from the hydrated cowpea meal was fried with the lid off for approximately 4-5 min with the balls being turned once to ensure even cooking. Akara made from WTM paste was fried with the lid off for 2-3 min with the balls being turned once to ensure even cooking. Based on preliminary trials, it was determined that akara processed from the hydrated meal pastes required additional cooking time to ensure complete cooking. The akara balls were then

removed from the oil and drained on absorbent paper towels. Akara was cooled to room temperature before objective measurements were taken.

Specific Gravity

Specific gravity of pastes prior to whipping and post whipping were determined in triplicate using the method described by Campbell, Penfield, & Griswold (1979). Paste was gently spooned into a dry ¹/₄ cup measuring cup, which was then tapped 10 times on the counter top to remove any air pockets. The paste was then leveled by scraping a spatula over the top of the cup; excess paste was wiped from the sides of the cup. The paste was weighed and the following formula was used to determine the specific gravity:

Water was weighed after being boiled and cooled to room temperature.

Viscosity

Viscosity of pastes prior to whipping and post whipping was measured using the method outlined by Singh et al. (2004). Approximately 100 ml of paste was gently spooned into a 250 ml beaker and the beaker was tapped 10 times to remove air pockets. Measurements were then taken with a Brookfield viscometer (HATD model, Stoughton, MA) equipped with a Model C Helipath and a TC spindle operated at 10 rpm. The viscometer and Helipath were leveled using the inbuilt levelers; viscosity was recorded in triplicate after the spindle had rotated 10 times in the sample with the Helipath turned on. Readings were taken in triplicate for each sample.

Texture

The method of Singh et al. (2004) was used to determine the hardness of the akara crumb. A sharp knife was used to cut a one cm³ sample from the crumb of an akara ball. The cube was then compressed in an Instron universal testing machine (Model 544, Instron, Inc., Canton, MA) 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 1000 mm/min, and the cube was compressed a second time to 2.5 mm under the same conditions. The measurements were taken in triplicate for each sample.

Statistical Analysis

Analysis of variance procedures were used to analyze the data (STATISTICA by StatSoft Version 6.1, 2003). Mean separation tests were performed by the LSD test (α =0.05).

Results and Discussion

Specific Gravity

Percent change of specific gravity after whipping is an indirect measure of the foamability of a paste as it expresses the amount of air incorporated upon whipping. Creation of a good foam is vitally important to akara quality. The incorporation of air into paste via whipping decreases density making the paste float during frying and resulting in a light and spongy end product. Researchers have demonstrated lower % change specific gravity in meal pastes than in WTM (traditionally wet milled paste) paste upon whipping (Kethireddipalli et al., 2002a; McWatters & Brantley, 1982; Ngoddy et al., 1986).

The pre and post-whip specific gravities of the samples are listed along with the % reduction after whipping in Table 2.2. Pre-whipping, the specific gravity of the WTM

paste (0.977) was lower than any of the meal pastes. FD2 (3L:1F) was the only paste with a post-whip specific gravity that was not significantly different from the WTM paste (0.637 and 0.627 respectively). However, there were several meal pastes, HM1 (2L:2F), HM5A (4L:0F), HM6 (0L:4F), FD5A (4L:0F) and FD5B (4L:0F), that had lower postwhip specific gravities. For each of those 5 samples, the % reduction was larger than that seen with the WTM paste. Although each of the three blends (HM5A, FD5A, FD5B) consisting of 35% large particles and no fine particles (4L:0F) had a lower post-whip specific gravity and larger % reduction than the WTM paste, they were all significantly different from one another. With the exception of the three blends (HM5A, FD5A, FD5B) consisting of 35% large particles and no fine particles (4L:0F), there was no correlation between the particle size blends and the specific gravity or the percent change in specific gravity.

As mentioned previously, the presence of proteins as well as cell wall material play a role in the foamability of cowpea paste. Kethireddipalli et al. (2002a and b) demonstrated a link between the availability of soluble proteins and the presence of cell wall material and the milling method used. The researchers showed that cells were disrupted in WTM paste whereas paste made from rehydrated meal had many more intact cells that did not release cell contents necessary to form a good foam. The researchers attributed this to the easy tearing of the turgid wet milled cells which allowed the contents to leak out. Kethireddipalli et al. (2002a) saw a reduction in specific gravity upon wet milling the hydrated meal pastes in a blender. Kerr, Ward, McWatters, & Resurreccion (2000) found that middling (particles collected on a 0.149 mm screen) cowpea flour fractions were high in proteins, however, the fine particles were the highest

in protein solubility which the researchers attributed to the level of disruption of cells necessary to produce such fine particles. In this study, all hydrated meal samples were wet milled in a blender prior to whipping which caused further disruption of cell components present and contributed to the overall good foamability shown by the samples and the lack of trends seen among the various PSDs.

Viscosity

Viscosity is a measurement of cowpea paste functionality and an indication of the handling characteristics of the paste. Viscosity of the liquid phase of a foam plays a role in the stability of that foam over time. A more viscous paste results in formation of smaller bubbles during whipping, and subsequently less liquid drains allowing the foam to hold up longer (Damodaran, 1994; Sikorski, 1997; Hanselmann & Windhab, 1999). Pastes with low viscosities become difficult to handle and do not dispense well in frying oil resulting in distorted akara with an inferior texture (McWatters, 1983).

Table 2.3 shows the pastes' viscosity (cP) prior to whipping and post whipping and the % reduction in viscosity after whipping. The values of the meal pastes were significantly lower than the WTM paste which was 119,773 cP pre-whip and 43,333 cP post-whip for a % reduction of 63.81. The high percent reduction was indicative of the excellent foaming ability of the WTM paste as more air incorporated into the paste decreased the viscosity. Only one other paste, HM4 (0L:0F), had a % reduction (64.39) not significantly different than that seen with WTM. Each sample (HM1, HM5A, HM6, FD5A, FD5B) that had lower post-whip specific gravities and larger % reduction in the specific gravity than WTM paste had lower viscosity than WTM paste both pre and postwhipping. Each of those 5 samples also had a lower % reduction in the viscosity after

whipping. McWatters (1983) showed that as the fine particles in cowpea flour increased (via mill screen size decreasing), the viscosity of cowpea paste made from the flour decreased. Decreasing particle size upon milling of plant material resulted in decreased water holding capacity (Auffret et al., 1994; Cadden, 1987; Han & Kahn, 1990a and b; Mongeau & Brassard, 1982). The two paste samples with the highest percentage of fine particles, HM6 (0L:4F) and FD6 (0L:4F), had very low % reductions, 10.73% and 10.16% respectively, indicating that the pastes had very little air incorporated during the whipping process. The low viscosity of sample FD6 (0L:4F) made the paste difficult to handle and made it impossible to prepare akara from it.

Texture Profile Analysis

As has been previously mentioned, akara made from processed dry meals and flours tends to be texturally inferior to and thus less acceptable than traditionally made akara. Akara consumers desire a product that is light and spongy, and the akara made from rehydrated meals and flours is reported as dense and lacking a spongy interior (Dovlo et al., 1976; McWatters, 1983). The change in particle shape and size after milling results in a more dense packing of particles when compared to whole peas (Robertson, de Monredon, Dysseler, Guillon, Amado, & Thibault, 2000). This phenomenon can result in a denser end product although the specific gravity of the paste may be relatively low. In a study conducted by McWatters et al. (1988), a positive correlation between objectively measured cohesiveness and sensory scores for sponginess was seen with a correlation coefficient of 0.86 ($p \le 0.05$). In the same study, correlation was also seen between measured hardness values and tenderness sensory scores with a coefficient of -0.85 ($p \le 0.05$). Cohesiveness represents the amount of force necessary to

chew a food thus indicating the strength of the internal bonds of that food, and hardness is the force necessary to take the first bite of the food (Friedman, Whitney, & Surmacka Szczesniak, 1963).

Samples HM5A, FD5A and FD5B, each with 35% large particles and no fine particles (4L:0F), all had lower post-whip specific gravities than the WTM sample, and each of the three samples had hardness values (5.317 N, 6.362 N, and 4.048 N respectively) which were not significantly different from the WTM value of 5.341 N. HM1 (2L:2F) and HM6 (0L:4F) also had post-whip specific gravities lower than WTM. HM1 (2L:2F) had a hardness value higher than WTM at 7.577 N. The hardness value of HM6 (0L:4F), 5.912 N, was not significantly different from for the WTM product. None of the cohesiveness values of the akara samples made from the various meal pastes were significantly different from the cohesiveness value for the WTM samples. Other than the low hardness values of the three blends (HM5A, FD5A, FD5B) consisting of 35% large particles and no fine particles (4L:0F), there was no trend seen in the texture profile of the samples with the same PSD.

Conclusions

Results from this study show that cowpea paste made from processed dry cowpea meal with a narrowly defined particle size distribution (65% particles in the range of 0.180 - 0.425 mm and 35% in the range of 0.425 - 1.000 mm) had the same functional properties as traditionally prepared cowpea paste and could be used to produce akara similar in quality to traditionally prepared akara regardless of whether the meal was processed via dry or wet milling. Blends HM5A (4L:0F) and FD5B (4L:0F) had specific gravity and viscosity values that were significantly different from WTM paste; however,

the differences did not result in adverse paste handling characteristics. Most notable, the textural values of samples from these two blends were not significantly different from WTM values suggesting the akara prepared from them would be acceptable to consumers. In order to determine the role of wet milling without thermal drying, freeze drying was chosen as a processing method for this study. Freeze drying is a relatively gentle drying process employed to minimize degradation caused by thermal processing and maintain the attributes (chemical, biological, physical and organoleptic) the product has in the fresh state. However, the freeze drying process consumed more resources (i.e. time and energy input) than the hammer milling process yet did not ultimately yield paste or akara that was of significantly higher quality than paste and akara prepared from the traditional wet mill process or from hammer milled meal. Therefore, the results of this study indicate that the less expensive and more accessible hammer milling process combined with particle size manipulation was adequate to produce a readily hydratable meal that could be used to make acceptable akara.

Acknowledgements

This research was funded by a grant from the Bean/Cowpea Collaborative Research Support Program, U.S. Agency for International Development (contract/grant number: DAN-1310-G-SS-6008-00). California Cream cowpeas used for this research were supplied by Inland Empire Foods, Riverside, California.
	Particle size distribution in terms of various fractions (%) ^b						
Blend # ^c	Large	Medium	Fine				
1	17.5	65	17.5				
(2L.2F)							
(22.21)							
2	26.25	65	8 75				
$(2I \cdot 1E)$	20.23	05	0.75				
(31.11)							
2	0.75	(5	26.25				
3	8.75	63	20.25				
(1L:3F)							
4	0	100	0				
4	0	100	0				
(0L:0F)							
		<i></i>	0				
5A	35	65	0				
(4L:0F)							
$5B^{a}$	35	65	0				
(4L:0F)							
6	0	65	35				
(0L:4F)							

Table 2.1 Particle size distribution of blends^a

^aBlends were made on a per weight basis

^bParticle size range in mm—Large: >0.425; Medium: 0.180 – 0.425; Fine: 0.045 – 0.180

^cEach blend consists of a minimum of 65% medium particles; the proportion of large (L) and fine (F) particles in the remaining 35% of the blend is listed below each blend number. ^dParticle size for large fraction had 3 subfractions of equal proportion; these subfractions were: 0.850 –

"Particle size for large fraction had 3 subfractions of equal proportion; these subfractions were: 0.850 - 1.000 mm, 0.600 - 0.850 mm, 0.425 - 0.600 mm.

				Specific Gravi	ty
Preparation Type	Sample ID	PSD^{b}	Pre-Whip	Post-Whip	% Reduction
WTM	WTM		0.977h	0.627 <i>f</i>	35.90g
Hammer Milled	HM1	2L:2F	1.045 <i>ab</i>	0.615 <i>g</i>	41.12 <i>bc</i>
	HM2	3L:1F	1.053 <i>a</i>	0.663 <i>c</i>	37.02 <i>ef</i>
	HM3	1L:3F	1.022 <i>d</i>	0.640 <i>e</i>	37.41 <i>ce</i>
	HM4	0L:0F	1.040 <i>b</i>	0.696 <i>b</i>	33.05h
	HM5A	4L:0F	0.995fg	0.552 <i>i</i>	42.90 <i>b</i>
	HM6	0L:4F	1.023 <i>d</i>	0.615 <i>g</i>	39.92 <i>c</i>
Freeze Dried	FD1	2L:2F	1.039 <i>abc</i>	0.653 <i>cd</i>	37.15 <i>ef</i>
	FD2	3L:1F	1.029 <i>dc</i>	0.637 <i>ef</i>	38.08 <i>de</i>
	FD3	1L:3F	1.021 <i>d</i>	0.652d	36.20 <i>cf</i>
	FD4	0L:0F	1.001 <i>ef</i>	0.687b	31.37 <i>i</i>
	FD5A	4L:0F	0.989 <i>g</i>	0.569h	44.50 <i>a</i>
	FD5B	4L:0F	1.006 <i>e</i>	0.614 <i>g</i>	38.94 <i>cd</i>
	FD6	0L:4F	0.993fg	0.831 <i>a</i>	16.24 <i>j</i>

Table 2.2 Effect of particle size distribution (PSD) of cowpea meal on specific gravity of cowpea paste during preparation of akara^a

^aValues are an average of three measurements. Mean values in a column not followed by the same letter are significantly different at α =0.05.

^b Each blend consists of a minimum of 65% medium particles, the proportion of large (L) and fine (F) particles in the remaining 35% of the blend is listed in the PSD column. For further details, see Table 2.1.

				Viscosity (cP)	
Preparation Type	Sample ID	PSD^{b}	Pre-Whip	Post-Whip	% Reduction
WTM	WTM		119,733 a	43,333 a	63.81 <i>a</i>
Hammer Milled	HM1	2L:2F	53,200 d	27,000 <i>cd</i>	49.25 <i>c</i>
	HM2 HM3	3L:1F 1L:3F	47,467 e 35.733 f	24,533 e 20.133 g	48.31 <i>c</i> 43.66 <i>d</i>
	HM4	0L:0F	75,067 b	26,733 d	64.39 <i>a</i>
	HM5A	4L:0F	65,067 c	28,200 b	56.66b
	HM6	0L:4F	25,467 h	22,733 f	10.73 <i>f</i>
Freeze Dried	FD1	2L:2F	29,733 g	19,000 h	36.10e
	FD2	3L:1F	45,733 e	27,667 bc	39.51 <i>e</i>
	FD3	1L:3F	22,133 i	11,067 <i>i</i>	50.00 <i>c</i>
	FD4	0L:0F	45,533 e	23,133 f	49.19 <i>c</i>
	FD5A	4L:0F	47,467 e	24,267 e	48.88 <i>c</i>
	FD5B	4L:0F	51,867 d	26,133 d	49.61 <i>c</i>
	FD6	0L:4F	6,600 j	5,933 j	10.16 <i>f</i>

Table 2.3 Effect of particle size distribution (PSD) of cowpea meal on viscosity of cowpea paste during preparation of akara^a

^aValues are an average of three measurements. Mean values in a column not followed by the same letter are significantly different at α =0.05.

^b Each blend consists of a minimum of 65% medium particles, the proportion of large (L) and fine (F) particles in the remaining 35% of the blend is listed in the PSD column. For further details, see Table 2.1.

Preparation Type	Sample ID	PSD^{b}	Hardness (N) ^c	Cohesiveness ^d
WTM	WTM		5.341 <i>de</i>	0.345 <i>a</i> - <i>g</i>
Hammer Milled	HM1	2L:2F	7.577 <i>bc</i>	0.359 <i>ae</i>
	HM2	3L:1F	6.377 <i>cd</i>	0.324bcdefg
	HM3	1L:3F	6.721 <i>cd</i>	0.383 <i>a</i>
	HM4	0L:0F	7.190 <i>bcd</i>	0.299fg
	HM5A	4L:0F	5.317 <i>de</i>	0.356 <i>af</i>
	HM6	0L:4F	5.912 <i>de</i>	0.373 <i>ab</i>
Freeze Dried	FD1	2L:2F	9.600 <i>dab</i>	0.361 <i>ad</i>
	FD2	3L:1F	10.225 <i>a</i>	0.316bcdefg
	FD3	1L:3F	10.504 <i>a</i>	0.364 <i>ac</i>
	FD4	0L:0F	10.385 <i>a</i>	0.302 <i>efg</i>
	FD5A	4L:0F	6.362 <i>cd</i>	0.314 <i>cdefg</i>
	FD5B	4L:0F	4.048 <i>e</i>	0.297g
	FD6	0L:4F	N/A ^e	N/A

Table 2.4 Effect of particle size distribution (PSD) of cowpea meal on textural properties of akara^a

^aValues are an average of three measurements. Mean values in a column not followed by the same letter are significantly different at α =0.05.

^b Each blend consists of a minimum of 65% medium particles, the proportion of large (L) and fine (F) particles in the remaining 35% of the blend is listed in the PSD column. For further details, see Table 2.1. ^cHardness = force required on the first chew

^dChewiness = force required on each chew (A_1/A_2)

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^eThe paste made from the FD6 meal was too fluid to dispense in frying oil making it impossible to produce akara.

References

Abbey, B. W., & Ibeh, G. O. (1988). Functional properties of raw and heat processed cowpea (*Vigna unguiculata*, Walp) flour. *Journal of Food Science*, *53* (6), 1775-1777, 1791.

Akpapunam, M. A., & Markakis, P. (1981). Protein supplementation of cowpeas with sesame and watermelon seeds. *Journal of Food Science*, 46 (3), 960-961.

AOAC. (1995). *Official Methods of Analysis of AOAC International*, (16th ed.). Arlington: Association of Official Analytical Chemists.

Auffret, A., Ralet, M-C., Guillon, F., Barry, J-L., & Thibault, J-F. (1994). Effect of grinding and experimental conditions on the measurement of hydration properties of dietary fibres. *Lebensmittel-Wissenschaft und-Technologie*, *27* (2), 166-172.

Boeh-Ocansey, O. (1989). Developments and challenges in Africa's food industry. *Food Technology*, 43 (5), 84-92.

Bressani, R. (1985). Nutritive value of cowpea. In S. R. Singh, K. O. Rachie, *Cowpea Research, Production and Utilization*, (pp. 353-359). Great Britain: John Wiley & Sons.

Bulgarelli, M. A., Beuchat, L. R., & McWatters, K. H. (1988). Microbiological quality of cowpea paste used to prepare Nigerian akara. *Journal of Food Science*, *53* (2), 442-444, 449.

Cadden, A-M. (1987). Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. *Journal of Food Science*, *52* (6), 1595-1599, 1631.

Campbell, A. M., Penfield, M. P., & Griswold, R. M. (1979). *The Experimental Study of Food*, (2nd ed.) (p. 475). Boston, MA: Houghton Mifflin.

Damodaran, S. (1994). Structure-function relationship of food proteins. In: N. S. Hettiarachchy, G. R. Ziegler, *Protein Functionality in Food Systems*, (pp. 1-38). New York: Marcel Dekker, Inc.

Damodaran, S. (1996). Amino Acids, peptides, and proteins. In O. R. Fennema, *Food Chemistry*, (3rd ed.) (pp. 321-429). New York: Marcel Dekker, Inc.

Dovlo, F. E., Williams, C. E., & Zoaka, L. (1976). *Cowpeas: Home Preparation and Use in West Africa*. (pp. 21-25, 29, 57). IDRC-055e. Ottawa: International Development Research Centre.

Enwere, N. J., McWatters, K. H., & Phillips, R. D. (1998). Effect of processing on some properties of cowpea (*Vigna unguiculata*), seed, protein, starch, flour and akara. *International Journal of Food Science and Nutrition*, *49*, 365-373.

Enwere, N. J., & Ngoddy, P. O. (1986). Effect of heat treatment on selected functional properties of cowpea flour. *Tropical Science*, *26*, 223-232.

Friedman, H. H., Whitney, J. E., & Surmacka Szczesniak, A. (1963). The texturometer— A new instrument for objective texture measurement. *Journal of Food Science*, *29*, 390-396.

Giami, S. Y. (1993). Effect of processing on the proximate composition and functional properties of cowpea (*Vigna unguiculata*) flour. *Food Chemistry*, 47, 153-158.

Giese, J. (1994). Proteins as ingredients: types, functions, applications. *Food Technology*, 48 (10), 50-60.

Han, J-Y., & Khan, K. (1990a). Physicochemical studies of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 384-390.

Han, J-Y., & Khan, K. (1990b). Functional properties of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 390-394.

Hanselmann. W., & Windhab, E. (1999). Flow characteristics and modelling of foam generation in a continuous rotor/stator mixer. *Journal of Food Engineering*, *38*, 393-405.

Henshaw, F. O., & Lawal, S. A. (1993). Effects of processing method on the functional properties of cowpea flour. *Tropical Science*, *33*, 377-385.

Henshaw, F. O., McWatters, K. H., Oguntunde, A. O. & Phillips, R. D. (1996). Pasting properties of cowpea flour: effects of soaking and decortication method. *Journal of Agricultural and Food Chemistry*, 44 (7), 1864-1870.

Kaur, M., & Singh, N. (2005). Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arientinam* L.) cultivars. *Food Chemistry*, *91*, 403-411.

Kerr, W. L., Ward, C. D. W., McWatters, K. H., & Resurreccion, A. V. A. (2000). Effect of milling and particle size on functionality and physicochemical properties of cowpea flour. *Cereal Chemistry*, 77 (2), 213-219.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002a). Effect of milling method (wet and dry) on the functional properties of cowpea (*Vigna unguiculata*) pastes and end product (akara) quality. *Journal of Food Science*, 67 (1), 48-52.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002b). Evaluating the role of cell wall material and soluble protein in the functionality of cowpea (*Vigna unguiculata*) pastes. *Journal of Food Science*, 67 (1), 53-59.

Marsili, R. (1993). Protein Power: Functionality and versatility. Food Product Design. Accessed from www.foodproductdesign.com/archive/1993/0993ap2.html on October 28, 2004.

McWatters, K. H. (1983). Compositional, physical and sensory characteristics of *akara* processed from cowpea paste and Nigerian cowpea flour. *Cereal Chemistry*, *60* (5), 333-336.

McWatters, K. H., & Brantley, B. B. (1982). Characteristics of akara prepared from cowpea paste and meal. *Food Technology*, *36*, 66-68.

McWatters, K. H., Chinnan, M. S., Hung, Y-C., & Branch, A. L. (1988). Effect of predecortication drying temperature on cowpea paste characteristics and functionality in preparation of akara. *Cereal Chemistry*, 65 (1), 23-27.

McWatters, K. H., Hung, C-Y. T., Hung, Y-C., & Chinnan, M. S. (2001). Akara-making characteristics of five U.S. varieties of cowpeas (*Vigna unguiculata*). *Journal of Food Quality*, *24*, 53-65.

Mongeau, R., & Brassard, R. (1982). Insoluble dietary fiber from breakfast cereals and brans: bile salt binding and water-holding capacity in relation to particle size. *Cereal Chemistry*, *59* (5), 413-417.

Nagmani, B., & Prakash, J. (1997). Functional properties of thermally treated legume flours. *International Journal of Food Science and Nutrition*, 48, 205-214.

Ngoddy, P. O., Enwere, N. J., & Onuorah, V. I. (1986). Cowpea flour performance in akara and moin-moin preparations. *Tropical Science*, *26*, 101-119.

Nnanyelugo, D. O., Ngoddy, P. O., Okeke, E. C., & Ngwu, E. K. (1997). Impact of a cowpea research project in Nigeria, using the rapid rural appraisal technique. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, & L. E. N. Jackai, *Advances in Cowpea Research*, (pp. 333-340). Ibadan, Nigeria: Co-publication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Sciences.

Phillips, R. D. (1993). Starchy legumes in human nutrition, health and culture. *Plant Food for Human Nutrition*, 44, 195-211.

Phillips, R. D., Chinnan, M. S., Branch, A. L., Miller, J., & McWatters, K. H. (1988). Effects of pretreatment on functional and nutritional properties of cowpea meal. *Journal of Food Science*, *53* (3), 805-809.

Phillips, R. D, & McWatters, K. H. (1991). Contribution of cowpeas to nutrition and health. *Food Technology*, 45 (9), 127-130.

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L. R., & Phillips, R. D. (1996). Cowpea flour: A potential ingredient in food products. *Critical Reviews in Food Science and Nutrition*, *36* (5), 413-436.

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J-F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *Lebensmittel-Wissenschaft und-Technologie*, *33* (2), 72-79.

Sikorski, Z. E. (1997). Proteins. In Z. E. Sikorski, *Chemical and Functional Properties of Food Components*, (pp. 119-160). Lancaster, Pennsylvania: Technomic Publishing Company, Inc.

Singh, A., Hung, Y-C., Phillips, R. D., Chinnan, M. S., & McWatters, K. H. (2004). Particle-size distribution of cowpea flours affects quality of akara (fried cowpea paste). *Journal of Food Science*, *69* (7), 243-249.

Uzogara, S. G., & Ofuya, Z. M. (1992). Processing and utilization of cowpeas in developing countries: a review. *Journal of Food Processing and Preservation*, *16*, 105-147.

SECTION IV

QUALITY AND CONSUMER ACCEPTANCE OF AKARA (fried cowpea paste) PROCESSED FROM WET AND DRY MILLED COWPEA (*Vigna unguiculata*) MEAL WITH SPECIFIED PARTICLE SIZE DISTRIBUTION ¹

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Abstract

Production of cowpea meal or flour that meets the needs of consumers and can be used to produce acceptable end products will increase cowpea utilization for traditional products and have potential for use in novel products. Direct quality indicators of cowpea paste and akara produced from traditionally wet milled peas and hammer milled (dry milled) and freeze dried (wet milled) meals were examined in this study. Both meal samples studied were formulated to consist of 65% medium sized particles and 35% large particles by weight. Particle volume mean diameters (µm) of the three paste samples were not significantly different from one another at the various stages during akara production. Scanning electron micrographs of akara crumb were converted to threshold images and analyzed. There was no significant difference in the amount of air found in the akara samples. Akara produced from both the meals was found acceptable by sensory panelists with no significant difference in any of the attributes or overall liking among the three samples.

Key words: cowpea, *Vigna unguiculata*, akara, cowpea meal, particle size distribution, functional properties, sensory evaluation

Introduction

Akara, deep fried cowpea paste, is the most commonly consumed cowpea derived food product in West Africa (Dovlo, Williams, & Zoaka, 1976). Cowpeas are a low cost highly nutritious dietary staple indigenous to Africa but grown today in many developing nations that provide protein, carbohydrates, vitamins and minerals (Boeh-Ocansey, 1989; Bressani, 1985; Phillips, 1993; Prinyawiwatkul, McWatters, Beuchat, & Phillips, 1996; Uzogara & Ofuya, 1992). The traditional process for preparing akara is very time consuming and labor intensive requiring the cowpeas to be soaked, manually decorticated and wet milled into paste. The resulting paste is then whipped and seasoned with salt, chopped onion and chopped hot or bell peppers (Dovlo et al., 1976). Microbial spoilage of the paste necessitates that it be used within several hours or be discarded, meaning paste can not be prepared ahead of time and stored (Bulgarelli, Beuchat, & McWatters, 1988). Akara is made by individuals in the home and purchased fully prepared from vendors in marketplaces (Phillips & McWatters, 1991). The outer crust of akara is crisp and the interior is spongy and bread-like. According to Enwere, McWatters, and Phillips (1998), the spongy interior of akara is crucial to consumer acceptance. Akara is often eaten as a snack food throughout the day or for breakfast with the customary serving size being approximately 100 grams (McWatters, 1983; McWatters, Hung, Hung, & Chinnan, 2001; Uzogara & Ofuya, 1992).

To simplify akara preparation, easy-to-use readily-hydratable cowpea flours and meals have been developed. Flours currently available on the commercial market meet the requirement of being convenient, but do not produce end products on par with freshly prepared products. Akara prepared from commercially available flours was without

typical and desired fresh cowpea flavor and had a dense, dry texture disliked by consumers (Dovlo et al., 1976; McWatters, 1983). Functional properties of paste made from hydrated flour or meal determine its acceptance as a starting material for akara (Phillips & McWatters, 1991). These properties are affected by the processing conditions to which cowpeas are subjected during preparation of the flour or meal.

The proteins found in cowpeas serve many purposes in paste and subsequent akara preparation. Foaming ability, the decisive functional property of cowpea paste in akara preparation, is dependent on protein quality as proteins act as surfactants by quickly absorbing water at the water-air interface and undergoing a rapid rearrangement to form a viscoelastic film around the air bubbles during the incorporation of air (Damodaran, 1994). However, proteins are somewhat delicate, and the increased temperatures endured during processing may alter conformation thus compromising functionality, which is dependant on physical structure and physico-chemical characteristics (Damodaran, 1996; Giese, 1994; Marsili, 1993). A protein's functionality is dependent not only on conformation, but also on solubility. Phillips, Chinnan, Branch, Miller, and McWatters (1988) demonstrated that changes seen in the specific gravity of cowpea paste paralleled changes seen in the solubility of cowpea proteins. Solubility of cowpea and other legume proteins has repeatedly been shown by researchers to be negatively affected by heat processing (Abbey & Ibeh, 1988; Enwere & Ngoddy, 1986; Henshaw & Lawal, 1993; Giami, 1993; Phillips et al., 1988; Nagmani & Prakash, 1997).

Research has linked poor performance of cowpea flours and meals to fine particle size resulting from intense milling (Kerr, Ward, McWatters, & Resurreccion, 2000; McWatters 1983; Ngoddy, Enwere, & Onuorah, 1986; Singh, Hung, Phillips, Chinnan, &

McWatters, 2004). Han and Kahn (1990a & b) milled and fractionated chick-peas and pinto and navy beans and found the fractions with a larger particle size (17.8 µm mean particle size) had superior water-holding capacity. Cadden (1987) found the cell wall matrix structure collapsed when sheared during milling, and Robertson, de Monredon, Dysseler, Guillon, Amado, and Thibault (2000) concluded that milling influences the hydration characteristics of plant fibers by altering the physical structure of the individual fibers and the physical arrangement of the particles. Hydration characteristics of cowpea meal used to make akara influence the final product (McWatters & Brantley, 1982). McWatters (1983) found that finely milled cowpea flour had a low level of hydration resulting in dry dense akara with a tough outer crust. The change in particle shape and size after milling results in a more dense packing of particles when compared to the whole peas thus resulting in a denser product (Robertson et al., 2000). A review of the properties of crumb structure of bread points out several studies that have linked the texture of bread crumb to density of the product. As density increases, so does firmness of the crumb (Scanlon & Zghal, 2001). The density is influenced by the volume fraction of air incorporated into the paste during whipping. It has been shown in past studies that finer more dense flours do not facilitate the incorporation of air during whipping (McWatters, 1983).

Kethireddipalli, Hung, McWatters, and Phillips (2002a & b) demonstrated a need for the presence of cell wall matrix in meal particles in order to produce an acceptable cowpea paste for use in making akara. The researchers microscopically examined the hydrated cellular material from wet milled cowpea paste and pastes produced from drymilled cowpea meal and flour and observed differences in both the amount of cell wall

material (CWM) present and the condition of the CWM. Significant amounts of cell wall matrix forming networks was seen in the wet milled material, where as cellular material from meal paste consisted of many intact cells. Finely milled flour also contained a significant amount of CWM, however, it lacked a network because of fine fragmentation during milling. The authors speculated that the wet-milling of the cowpeas allowed for facile release of cell contents, including cell wall material, by easy rupture of turgid cells. The authors attributed the improved hydration and foaming characteristics and the superior texture of the akara made from the wet milled paste to the presence of the light and fluffy cell wall matrix.

In a related study (Vanchina, Chinnan, & McWatters, 2005), indirect quality indicators (i.e. paste specific gravity and viscosity and akara texture) were measured for paste and akara made from two types of cowpea meal: a dry milled meal processed by hammer milling cowpeas using a 2.54 mm screen and a wet milled meal processed by grinding soaked peas into a paste which was then freeze dried and ground into meal. Both meals were fractionated via sieving and blends of pre-determined particle size distribution were made. The study indicated that the differently milled cowpea meals both performed similarly to traditionally wet milled cowpeas in the indirect quality experiments when the particle size distribution of the meals was set at 65% medium particles (0.180 - 0.425 mm) and 35% large particles (0.425 - 1.000 mm). The current study examined the particle size distribution of those two cowpea meals during the akara making process; the physical structure and consumer acceptance of akara made from the meals was also studied to determine if acceptable akara could be produced using dry cowpea meal as a starting material.

Materials and Methods

Processing of Cowpea Meals

An all cream cultivar of cowpea known as California Cream (*Vigna unguiculata*, breeding line UCR 97-15-33) was used for this study. The cowpeas were obtained from Inland Empire Foods, Riverside, California. Seeds were stored in a plastic container with a tight fitting lid at 4° C until used. Moisture content of intact seeds was determined, by calculating weight difference after drying in a vacuum oven (Fisher Scientific Isotemp Vacuum Oven, Model 285A) for 24 hours at 70° C 25mm Hg, to be 9.68% (modified AOAC method 925.09, AOAC, 1995).

Freeze Dried Meal

Batches of cowpeas (approximately 0.8 kg) were placed in a deep tray, covered with tap water, and soaked approximately 18 hours. The drained seeds were ground undecorticated in a Hobart Commercial Food Chopper (model 4812, Troy, OH) through a series of plates: first a plate with 4.763 mm (3/16 in) diameter holes immediately followed by a plate with 3.175 mm (2/16 in) diameter holes to obtain a fine paste without causing the grinder to gum up. The paste was frozen in a -18° C freezer (approximately 24 hours) in plastic pans lined with wax paper. The frozen cowpea paste was freeze dried using a Genesis SQ25 Super ES freeze drier (The VirTis Co., Gardiner, NY). When the internal temperature of the paste equilibrated with the temperature of the heat source (the shelves holding the trays), the drying was determined to be completed. The dried cowpea paste was then ground using a plate mill (Model 4E Grinding Mill, The Straub Co., Hatboro, PA) with the plates tightened to the lowest clearance (approximately 2.75 mm).

Final moisture content of the freeze dried cowpea meal (FD) was determined to be 4.99%.

Hammer Milled Meal

A Champion hammer mill (model 6 x 14, Champion Products Inc., Eden Prairie, MN) was used to dry mill the cowpeas using a 2.54 mm screen. Final moisture content of the hammer milled cowpea meal (HM) was determined to be 10.68%.

Meal Fractionation and Particle Size Blends

One hundred g of meal was sieved by mechanical shaking (RX-86, W.S. Tyler, Mentor, OH) using a series of sieves (#40, 100, 400) and a collection pan (USA Standard Testing Sieve, ASTME II Specification, Fisher Scientific, Pittsburgh, PA) for 10 min in order to fractionate the meals. For the freeze dried meal, the fraction collected from the #40 sieve was further fractionated using sieves #18, 20, 30 and a collection pan following the same procedure.

Researchers have reported that a minimum of 65% medium sized particles (0.180 – 0.425 mm) is necessary for proper functionality of cowpea meal used to make akara (Henshaw et al., 1996; Ngoddy et al., 1986). Therefore, the hammer milled and freeze dried samples prepared for this study both had a minimum of 65% medium particles. The remaining 35% consisted of large (>0.425 mm) particles. The particle size distribution (PSD) of the freeze dried large fraction consisted of 3 subfractions of equal proportion: 1.000 - 0.850 mm, 0.600 - 0.850 mm, and 0.425 - 0.600 mm. This blend mirrored the overall PSD of the hammer milled meal and was determined in a related study (Vanchina et al., 2005) to have superior functional properties. Meal was vacuum sealed in high density barrier bags and stored at 4° C until needed.

Preparation of Cowpea Pastes

Traditional wet milled paste (WTM)

Cowpea paste processed by the traditional method employing wet milled peas (WTM) was used as the control for all experiments. The paste was made by the method described by McWatters et al. (2001). Dry cowpeas were weighed and soaked in tap water for 3 hours. After draining 5 min, the cowpeas were weighed and placed in a mini food chopper (Sunbeam Oskar, Model 14081, Oak Brook, IL) and chopped for 90 seconds with scraping every 30 seconds. A necessary amount of water was added to the chopped peas to bring the moisture content of the paste to 65%. The following equation, modified to account for the use of cream variety cowpeas that did not require decortication, was used to calculate the amount of water added:

$$[W_a = W_1(100 - M_i/100 - M_f) - W_s]$$

where W_a is the weight of water needed to bring moisture content of paste to the target moisture content

- W₁ is the initial weight of dry seeds
- M₁ is the moisture content of dry seeds
- M_f is the target moisture content of paste
- W_s is the weight of seeds after soaking 3 hours and draining 5 min

The chopped peas were blended (Osterizer blender, model no. 6641, Sunbeam Products, Inc., Boca Raton, FL) on the "Low" speed "Blend" setting for 90 seconds with

the sides of the blender jar scraped every 30 seconds. The blended paste was transferred into a bowl and whipped using a hand mixer (model no. 2486, Sunbeam Products, Inc., Hattiesburg, MS) with a whisk attachment for 90 seconds on the highest speed setting (#6).

Meal pastes

Meal was hydrated by adding the amount of water necessary to bring the moisture content of the paste up to 65%. The water was added slowly with constant gentle stirring to ensure uniform wetting, and the meal was hydrated for 15 min. The hydrated paste was transferred into the Osterizer blender and blended on the "Low" speed "Blend" setting for 90 seconds for 30 second intervals with scraping and stirring in between. The paste was then transferred into a bowl and whipped using the Sunbeam hand mixer for 90 seconds on the highest speed setting (#6).

Particle Size Distribution (PSD)

Singh et al. (2004) developed a method for wet PSD measurements of cowpea paste by laser diffraction using a Mastersizer S (Malvern Instruments, Worcestershire, U.K.). Cowpea paste samples were prepared as if akara was being made. After blending and again after whipping, 1 g of each paste sample was diluted in 100 mL deionized water. The diluted sample was then loaded into the volume presentation unit of the instrument, which contained 120 mL of deionized water, using a pipette until the obscuration level reached 13%. Overall particle concentration is indicated by the obscuration level, which is the fraction of light lost from the main beam upon introduction of the sample into the presentation unit. The Malvern optical mode calculated the relative volume distribution of particles and other size distribution

parameters from the light scattering data using the equivalent sphere approach. Software used by the instrument reported the volume mean diameter (μ m) of the samples. The Mastersizer required the refractive indices of the liquid used for dispersion and the sample being analyzed; however, no such indices exist for cowpea paste. Therefore, the wet standard presentation was used to calculate the PSD of the pastes. The measurements were carried out in triplicate.

Preparation of Akara

Akara for SEM Micrograph

Akara was made by the procedure described by McWatters et al. (2001). The whipped paste was portioned with a stainless steel scoop (#40, approximately 30 ml [7/8 oz] capacity, The ABC Collection, Japan) into hot peanut oil preheated to 193° C in a counter-top deep-fat fryer (Presto Kitchen Kettle Electric Multi Cooker, model no. 06000-04, National Presto Industries, Eau Claire, WI). Akara made from each of the cowpea meals was fried with the lid off for approximately 4-5 min, whereas akara made from WTM paste was fried with the lid off for 2-3 min. Based on preliminary trials, it was determined that akara processed from the hydrated meal pastes required additional cooking time to ensure complete cooking. The balls were turned once approximately half way through cooking to ensure even cooking. The akara balls were removed from the oil and drained on absorbent paper towels. Akara was cooled to room temperature before being placed in zipper close bags and refrigerated overnight.

Akara for Sensory Evaluation

Akara was made by the procedure described by Patterson, McWatters, Hung, Chinnan, and Phillips (2002). Pastes were prepared as detailed above. Seasonings (1.5% salt, 9.5% chopped onion and 9.5% chopped green bell pepper) were gently folded into the whipped paste. The seasoned whipped paste was portioned with a stainless steel scoop (#40, approximately 30 ml capacity, The ABC Collection, Japan) into hot (preheated to 193° C) peanut oil in a deep-fat fryer (Presto Kitchen Kettle Electric Multi Cooker, model no. 06000-04, National Presto Industries, Eau Claire, WI). The akara made from the cowpea meal was fried with the lid off for 2.5 min; the balls were then turned and fried for an additional 2 min. Akara made from traditionally wet-milled cowpea paste was fried for 2 min with the balls being turned after one min to ensure even cooking. The akara balls were then removed from the oil and drained on absorbent paper towels. Akara was cooled to room temperature before being placed in a single layer in large zipper-closed freezer bags and stored in the refrigerator.

Scanning Electron Microscopy (SEM)

CryoSEM was chosen for this sample as it allows for relatively quick preparation in comparison to traditional chemical fixation which was not necessary for this sample. Sections of approximately 2 mm thickness were cut from the crumb of akara with a razor blade. Each section was then mounted on an SEM stub with Tissue Tek mixed with conductive carbon dust and rapidly frozen in liquid nitrogen slush (approximately -206°C) before being transferred to the Gatan Alto 2500 Cryostage and cryoprep chamber (Gavan UK, Ferrymills, Oxford, UK), which was maintained at -110 C°. The frozen samples were then sublimated to remove any ice on the surface of the sample and coated with approximately 20 nm of gold-palladium before being moved to the cryostage within the SEM (LEO 982 Field emission scanning electron microscope [FE-SEM] LEO Electron Microsopy, Inc., Thornwood, NY). The samples remained at -110 C° during

imaging. The samples were examined and photographed at an accelerating voltage of 5kV. Three samples from each type of akara were examined and four images were captured from each sample.

The SEM micrographs were converted into threshold images (i.e. the image was segmented so the pixels associated with air voids were black and those associated with crumb structure were white). Image analysis software (ImageJ, National Institute of Mental Health, Bethesda, MD, USA) was then used to count the pixels and determine the percentage of black pixels and the percentage of white pixels in the image.

Sensory Evaluation

An untrained consumer panel (n=64) was recruited from the University of Georgia Department of Food Science and Technology (Griffin, GA) database to determine the consumer acceptability of the akara. The criteria designated for participation in this test were a minimum age of 18 years, absence of any allergies related to ingredients being used to prepare the sample and availability for the test. Participants received a 10 dollar honorarium.

A standard 9-point hedonic scale (9=like extremely, 5=neither like nor dislike, 1=dislike extremely) was used by panelists to evaluate appearance, color, aroma, flavor, texture, and overall liking of the three samples. The ballot is shown in Figure 3.1. The panelists signed a consent form and completed a demographic questionnaire (Figure 3.2) upon arrival. They also completed a short questionnaire on their consumption of fried foods (Figure 3.3) after completing the tasting.

Akara samples were served warm with all panelists of a given session receiving the same coded sample at the same time. The sample reheating order was randomized among the sessions. Samples, which had been fully prepared one day prior to the sensory panel, were reheated from refrigeration temperature at 204° C for 6 min (reaching an internal temperature of 105° to 110° C) and served warm in a plastic soufflé cup. Panelists were asked to eat at least half of the sample, encouraged to expectorate the sample, and instructed to eat unsalted saltine crackers and rinse their mouths with water between samples.

Statistical Analysis

Analysis of variance procedures were used to analyze particle size distribution data (STATISTICA by StatSoft Version 6.1, 2003) and sensory ratings (SAS Inst. Release 6.12, 1996). Mean separation tests were performed by the LSD test (α =0.05).

Results and Discussion

Particle Size Distribution

Although the particle size distribution (PSD) of the meals used in this study was determined, the meals underwent additional processing throughout the akara making process that further reduced particle size. Past researchers have reported that this further reduction in particle size plays a role in the acceptance of dry cowpea meal as a starting material for making akara (Kethireddipalli 2002 a & b; Singh, 2004). Therefore, the particle size distribution of the pastes was examined at the different stages of the akara-making process to determine the extent of the influence of wet or dry milling on the functionality of meal pastes during processing. The volume mean particle sizes (μ m) of the post-blended and post-whipped samples and the percent change in volume mean diameters for the three samples, WTM paste, paste from hammer milled meal (HM) and paste from freeze

dried meal (FD), were not significantly different, 246.60 μ m, 218.02 μ m, and 200.25 μ m respectively. After whipping, the PSD for the WTM sample was reduced by 23.86% compared to only 9.69% for the HM sample and 4.72% for the FD sample. However, for each of the three samples, the volume mean diameters after whipping (187.75 μ m, 196.89 μ m, and 190.79 μ m respectively) were not significantly different from one another.

Several past studies have reported that PSD of cowpea meal is influential in the making of akara, and the meal must consist of a minimum of 65% medium-sized particles (Henshaw, McWatters, Oguntunde, & Phillips, 1996; Kethireddipalli et al., 2002a & b; McWatters, 1983; Ngoddy et al., 1986; Singh et al., 2004). McWatters (1983) sieved traditionally wet milled cowpea paste that had been alcohol-washed several times and air dried overnight and found 63.6% of the particles fell into the medium size range. However, in addition to reducing particle size, milling also alters the shape and size of particles resulting in more dense packing of particles when compared to whole peas (Robertson et al., 2000). This phenomenon can result in a denser end product although the particle size distribution itself may not be significantly different. The Mastersizer uses the equivalent sphere approach when measuring particle size meaning it assumes that all the particles in the system are spherical even when they may not be. Therefore, it is difficult to determine if potential particle shape differences between the meal particles and the WTM particles had any role. The upper range of the lens used by the Mastersizer S is only 837 microns meaning there were limitations in the measurement of PSD. In addition, the sample size was relatively small (1g from approximately 200 - 250g of paste), which could result in the data being heavily influenced by the presence of one large particle in the sample. Therefore, the PSD measurements were taken only after

blending and after whipping of the paste when the processing dictates that the particles will be at their smallest.

SEM Micrographs

The SEM micrographs of the akara crumb prepared from WTM peas, hammer milled meal and freeze dried meal are shown in Figures 3.4 through 3.6 respectively. The crumb of all three akara samples was very sponge-like with many small and large air pockets. In a related study (Vanchina et al., 2005), cohesiveness measurements for the three samples being examined in this study were not significantly different. Cohesiveness represents the amount of force necessary to chew a food thus indicating the strength of the internal bonds of that food (Friedman, Whitney, & Surmacka Szczesniak, 1963). Cohesiveness is an indication of the sponginess of a product which is a function of the amount of air incorporated into the paste during whipping (McWatters, Chinnan, Hung , & Branch, 1988). The micrographs of all three akara samples show significant incorporation of air and the formation of a web-like network in the akara.

The threshold images are shown in Figures 3.7 - 3.9. Image analysis supported the visual observations. The black pixels in the images represent air voids in the samples. The percentage of the black pixels in the image represented the quantity of air found in the sample (note that the bottom borders on the images were not included in the image analysis). The average percentages of black pixels for the three samples were not significantly different. The images of the wet milled sample had 73.20% black pixels, the hammer milled had 77.07%, and the freeze dried had 73.13%. The minimal differences in the SEM micrographs and the similar cohesiveness values seen in the

related study (Vanchina et al., 2005) indicated that both the freeze dried and hammer milled meals should produce akara that would be found acceptable by consumers.

Sensory Evaluation

Panelists provided responses to a demographic questionnaire which are summarized in Table 3.2. Panelists were 78.1% female and 21.9% male and ranged in age from 18 to 75. The majority (65.6%) of panelists were married. About 28% were high school graduates and over 20% had at least a college degree. Household income was relatively evenly distributed among the categories and the panelists were mostly either employed full time (40.6%) or retired (31.3%). The panel was about 80% white and 17% black.

In response to a questionnaire inquiring about their consumption of fried foods (Table 3.3), almost a third of the panelists (29.7%) reported that they ate away from home at least once a day. Over 56% of the panelists reported eating fried food more than once a week, and an additional 14% responded that they ate fried food daily. For 62.5% of the panelists, taste was the most important attribute when eating fried food with only 6.3% claiming that nutrition was the dominate consideration. In response to where they would most likely eat akara, 51.6% reported they would eat the product in a restaurant or cafeteria and 29.7% said a fast food establishment. About 45% of the panelists would eat akara as they would bread, and 32.8% would eat it as a side dish.

Table 3.4 shows the mean sensory ratings for akara prepared from traditionally wet milled cowpeas and hammer milled and freeze dried meals. For all three samples, each attribute (appearance, color, aroma, flavor, texture) measured and overall liking received ratings above 6 (like slightly). The overall liking ratings of the WTM samples

(6.6), the hammer milled sample (6.5), and the freeze dried sample (6.2) were not significantly different indicating that the two experimental samples produced akara that was considered acceptable by consumers. Comments most often made by panelists about the akara were similar for the three samples with too greasy, too bland and too dry being the most frequent. However, the comments were made with the same frequency about each of the samples further supporting the observation that panelists could not differentiate between samples. These data showed that the readily hydratable meal can be used to make acceptable akara. Of the two meals examined, the hammer milled meal was relatively easy to process, and akara made from the meal required less time and labor than akara made from whole peas.

Conclusions

The mean volume particle diameters of both the freeze dried and hammer milled meal pastes examined in this study were not significantly different from WTM paste throughout the akara-making process. The akara produced using both meals had an internal crumb structure closely resembling that seen with the traditionally prepared akara, and there was no significant difference in the quantity of air found in the different samples. The sensory ratings of the three akara samples for overall liking and all attributes were not significantly different. Controlling the particle size distribution of cowpea meal to be 65% medium particles (0.180 - 0.425 mm) and 35% large particles (0.425 mm - 1.000 mm) resulted in meal that was acceptable for use in making akara regardless of the milling method used (wet or dry). Due to the low temperature and absence of oxygen during the freeze drying process, degradation of components of the cowpea was minimized allowing the chemical, biological, physical, and organoleptic

attributes to remain similar to those found in the unprocessed product. Therefore, for this study freeze drying was chosen as a processing method that would allow for wet milling and drying without the use of heat. The freeze drying process required significantly more resources (i.e. time and energy) than the hammer milling process. Also, the freeze drying technology is not as readily accessible as the simpler to master hammer mill, which requires no technical knowledge to use effectively. For these reasons, it is evident that the benefits of freeze drying cowpea meal do not outweigh the costs, and an acceptable meal can be produced using the less expensive hammer milling process.

Acknowledgements

This research was funded by a grant from the Bean/Cowpea Collaborative Research Support Program, U.S. Agency for International Development (contract/grant number: DAN-1310-G-SS-6008-00). Inland Empire Foods (Riverside, California) supplied the cowpeas for this work. Special thanks to Sue Ellen McCullough, Sandra Walker, Chun Fang, and Dr. John Shields (The University of Georgia, Center for Ultrastructural Research) for providing technical assistance that contributed to the completion of this work.

Figure 3.1 Ballot used by sensory panelists to score akara

Panelist Code: _____ Date: _____

Please evaluate this product and check the space that best reflects your feeling about the product for all 6 questions. You may write comments in the space provided below.

1. How would you rate the "APPEARANCE" of this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

2. How would you rate the "COLOR" of this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

3. How would you rate the "AROMA" of this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

4. How would you rate the "FLAVOR" of this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

5. How would you rate the "TEXTURE" of this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

6. OVERALL, how do you (Like) this product?

Dislike	Dislike	Dislike	Dislike	Neither Like	Like	Like	Like	Like
Extremely	Very Much	Moderately	Slightly	Nor Dislike	Slightly	Moderately	Very Much	Extremely
[]	[]	[]	[]	[]	[]	[]	[]	[]
1	2	3	4	5	6	7	8	9

Comments (optional)

Figure 3.2 Demographic questionnaire completed by sensory panelists

Panelist Code:	Date:
Please answer all questions. All information is confidential a	nd will not be identified with your name.
1. What is your age group? (Please check ONE) 18-24 years old 25-34 years old 45-54 years old 55-64 years old	_ 35-44 years old _ 65-74 years old 75 yrs or older
2. What is your gender? (Please check ONE) Male Female	
3. Which do you consider yourself to be? (Please chec White Black Spanish/HispanicAsian	k ONE) Other (please specify)
4. What is your marital status? (Please check ONE) Never married Married Sep	arated, Divorced Widowed
 5. Level of education? (Please check the one which best	st applies to you) ent e (<4yrs) masters, Ph.D., law, medicine, etc.)
 6. Please check the one which best applies to you: Employed full-time Employed part-time Unemployed Retired 	
 7. What was the approximate level of your household incomunder \$10,000 \$10,000 to \$19,999 \$20,000 to \$29,999 \$30,000 to \$39,999 	ne before taxes last year? (Please check ONE) \$40,000 to \$49,999 \$50,000 to \$59,999 \$60,000 to \$69,999 \$70,000 and over

Figure 3.3 Fried food consumption questionnaire completed by sensory panelists

Date: _____

Panelist Code

1. How often do you eat fried foods?

Once a day Once a week Twice a week Less than once a week

2. What is the most important thing when eating this type of food?

Color Taste Texture Aroma/odor Nutrition Doneness Other

3. How often do you eat away from home?

Once a day Twice a day

More than twice a day

Once a week

Twice a week

Less than once a week

4. Where are you most likely to eat this type of food?

Fast food establishment Restaurant/Cafeteria

Home

5. In what way would you most likely eat this type of product?

Snack food	
Appetizer	
Side Dish	
Main Course	
Bread	
Other	

	Particle Size Distribution		
	(volume mean diameter, µm)		
Sample	Post-Blend	Post-Whip	% Reduction
WTM	246.60 <i>a</i>	187.75 <i>a</i>	23.86 <i>a</i>
Hammer Milled ^b	218.02 <i>a</i>	196.89 <i>a</i>	9.69 <i>ab</i>
Freeze Dried ^c	200.25 <i>a</i>	190.79 <i>a</i>	4.72 <i>b</i>

Table 3.1 Effect of blending and whipping of cowpea paste on particle size^a

^aValues are an average of three measurements. Mean values in a column not followed by the same letter are significantly different at α =0.05.

^bThe particle size distribution of the dry milled meal processed in a hammer milled meal was 65% medium particles: 0.180 - 0.425 mm and 35% large particles: 1.000 - 0.425 mm.

^cThe particle size distribution of the wet milled meal processed via freeze drying cowpea paste was 65% medium particles: 0.180 - 0.425mm and 35% large particles consisting of 3 subfractions of equal proportion; these subfractions were: 1.000 - 0.850mm, 0.600 - 0.850 mm, 0.425 - 0.600 mm

Demographic Data	% Responding
1. What is your age group? (n=64)	/o responding
18-24 years old	6.3
25-34 years old	20.3
35-44 years old	10.9
45-54 years old	20.3
55-64 years old	21.9
65-74 years old	14.1
75 + years old	6.3
2. What is your gender? (n=64)	
Male	21.9
Female	78.1
3. Which do you consider yourself to be? (n=64)	
White	79.7
Black	17.2
Spanish/Hispanic	3.1
Asian	0.0
Other	0.0
4. What is your marital status? (n=64)	
Never married	12.5
Married	65.6
Separated/Divorced	/.8
widowed	14.1
5. Level of education? (n=64)	
Less than 8 years of school	0.0
9-12 years of school	20.3
Graduated high school or equivalent	28.1
Vocational school or some college	31.3
Completed college	15.6
Graduate or professional school	4.7
6. Please check the one which best applies to you: $(n=64)$	
Employed full-time	40.6
Employed part-time	7.8
Unemployed	20.3
Retired	31.3
7. What was the approximate level of your household income before taxes last year? $(n=64)$	
Under 10,000	9.4
10,000-19,999	21.9
20,000-29,999	12.5
30,000-39,999	12.5
40,000-49,999	17.2
50,000-59,999	3.1
60,000-69,999	9.4
70,000 an over	14.1

 Table 3.2 Sensory panel demographic questionnaire

Consumption Data	% Responding
1. How often do you eat fried foods? (n=64)	<u> </u>
Once a day	14.1
Once a week	14.1
Twice a week	56.3
Less than once a week	15.6
2. What is the most important thing when eating this type of food? (n=64)	
Color	4.7
Taste	62.5
Texture	6.3
Aroma/odor	9.4
Nutrition	6.3
Doneness	10.9
Other	
2 How often do you get away from home? $(n=64)$	
S. How often do you cat away from nome? (11–04)	22.4
Truice a day	23.4
I wice a day	1.0
Or a structure a day	4./
Unce a week	18.8
I wice a week	45.3
Less than once a week	6.3
4. Where are you most likely to eat this type of food? $(n=64)$	
Fast food establishment	29.7
Restaurant/Cafeteria	51.6
Home	18.8
5. In what way would you most likely eat this type of product? (n=64)	
Snack food	1.6
Appetizer	9.4
Side dish	32.8
Main course	10.9
Bread	45.3
Other	0.0

Table 3.3 Sensory panel fried food consumption questionnaire

•	Traditional Wet	Hammer Milled	Freeze Dried
Attribute	Milled	Meal ^b	Meal ^c
Appearance	7.3	7.3	7.6
Color	7.4	7.5	7.6
Aroma	6.8	6.8	6.6
Flavor	6.3	6.4	6.0
Texture	6.4	6.3	6.2
Overall Liking	6.6	6.5	6.2

Table 3.4 Mean hedonic ratings for acceptability of akara made from traditional wet milled paste and cowpea meal processed by different methods with defined particle size distributions^a

^aMean values are based on a 9-point hedonic scale with 1=dislike extremely to 9=like extremely. For all attributes and overall liking, no significant difference was seen at α =0.05.

^bThe particle size distribution of the dry milled meal processed in a hammer milled meal was 65% medium particles: 0.180 - 0.425 mm and 35% large particles: 1.000 - 0.425 mm.

^oThe particle size distribution of the wet milled meal processed via freeze drying cowpea paste was 65% medium particles: 0.180 - 0.425mm and 35% large particles consisting of 3 subfractions of equal proportion; these subfractions were: 1.000 - 0.850mm, 0.600 - 0.850 mm, 0.425 - 0.600 mm.



Figure 3.4 Three SEM micrographs of the crumb of akara processed from traditionally wet milled cowpea paste



Figure 3.5 Three SEM micrographs of the crumb of akara processed from hydrated dry milled (hammer mill) cowpea meal with a particle size distribution of 65% particles in the medium range (0.180 - 0.425 mm) and 35% particles in the large range (1.00 - 0.425 mm).


Figure 3.6 Three SEM micrographs of the crumb of akara processed from hydrated wet milled and freeze dried cowpea meal with a particle size distribution of 65% particles in the medium range (0.180 - 0.425 mm) and 35% particles in the large range (1.00 - 0.425 mm). Large fraction had 3 subfractions of equal proportion; these subfractions were: 1.00 - 0.850 mm, 0.600 - 0.850 mm, and 0.425 - 0.600 mm.



Figure 3.7 Three threshold images of the crumb of akara processed from traditionally wet milled cowpea paste. Black pixels (73.08% average among the three images) represent air voids and white pixels (26.92%) represent crumb structure.



Figure 3.8 Three threshold images of the crumb of akara processed from hydrated dry milled (hammer mill) cowpea meal with a particle size distribution of 65% particles in the medium range (0.180 - 0.425 mm) and 35% particles in the large range (1.00 - 0.425 mm). Black pixels (77.07% average among the three images) represent air voids and white pixels (22.93%) represent crumb structure.



Figure 3.9 Three threshold images of the crumb of akara processed from hydrated wet milled and freeze dried cowpea meal with a particle size distribution of 65% particles in the medium range (0.180 - 0.425 mm) and 35% particles in the large range (1.00 - 0.425 mm). Large fraction had 3 subfractions of equal proportion; these subfractions were: 1.00 - 0.850 mm, 0.600 - 0.850 mm, and 0.425 - 0.600 mm. Black pixels (73.13% average among the three images) represent air voids and white pixels (26.87%) represent crumb structure.

References

Abbey, B. W., & Ibeh, G. O. (1988). Functional properties of raw and heat processed cowpea (*Vigna unguiculata*, walp) flour. *Journal of Food Science*, *53* (6), 1775-1777, 1791.

AOAC. 1995. *Official Methods of Analysis of AOAC International*, (16th ed.). Arlington: Association of Official Analytical Chemists.

Boeh-Ocansey, O. (1989). Developments and challenges in Africa's food industry. *Food Technology*, 43 (5), 84-92.

Bressani, R. (1985). Nutritive value of cowpea. In S. R. Singh, K. O. Rachie, *Cowpea Research, Production and Utilization*, (pp.353-359). Great Britain: John Wiley & Sons.

Bulgarelli, M. A., Beuchat, L. R., & McWatters, K. H. (1988). Microbiological quality of cowpea paste used to prepare Nigerian akara. *Journal of Food Science*, *53* (2), 442-444, 449.

Cadden, A-M. (1987). Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. *Journal of Food Science*, *52* (6), 1595-1599, 1631.

Damodaran, S. (1994). Structure-function relationship of food proteins. In N. S. Hettiarachchy, G. R. Ziegler, *Protein Functionality in Food Systems*, (pp. 1-38). New York: Marcel Dekker, Inc.

Damodaran, S. (1996). Amino Acids, peptides, and proteins. In O. R. Fennema, *Food Chemistry*, (3rd ed.) (pp. 321-429). New York: Marcel Dekker, Inc.

Dovlo, F. E., Williams, C. E., & Zoaka, L. (1976). *Cowpeas: Home Preparation and Use in West Africa*. IDRC-055e. Ottawa: International Development Research Centre.

Enwere, N. J., McWatters, K. H., & Phillips, R. D. (1998). Effect of processing on some properties of cowpea (*Vigna unguiculata*), seed, protein, starch, flour and akara. *International Journal of Food Science and Nutrition*, *49*, 365-373.

Enwere, N. J., & Ngoddy, P. O. (1986). Effect of heat treatment on selected functional properties of cowpea flour. *Tropical Science*, *26*, 223-232.

Friedman, H. H., Whitney, J. E., & Surmacka Szczesniak, A. (1963). The texturometer— A new instrument for objective texture measurement. *Journal of Food Science*, *29*, 390-396.

Giami, S. Y. (1993). Effect of processing on the proximate composition and functional properties of cowpea (*Vigna unguiculata*) flour. *Food Chemistry*, 47, 153-158.

Giese, J. (1994). Proteins as ingredients: types, functions, applications. *Food Technology*, 48 (10), 50-60.

Han, J-Y., & Khan, K. (1990a). Physicochemical studies of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 384-390.

Han, J-Y., & Khan, K. (1990b). Functional properties of pin-milled and air-classified dry edible bean fractions. *Cereal Chemistry*, 67 (4), 390-394.

Henshaw, F. O., & Lawal, S. A. (1993). Effects of processing method on the functional properties of cowpea flour. *Tropical Science*, *33*, 377-385.

Henshaw, F. O., McWatters, K. H., Oguntunde, A. O., & Phillips, R. D. (1996). Pasting properties of cowpea flour: effects of soaking and decortication method. *Journal of Agricultural and Food Chemistry*, 44 (7), 1864-1870.

Kerr, W. L., Ward, C. D. W., McWatters, K. H., & Resurreccion, A. V. A. (2000). Effect of milling and particle size on functionality and physicochemical properties of cowpea flour. *Cereal Chemistry*, 77 (2), 213-219.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002a). Effect of milling method (wet and dry) on the functional properties of cowpea (*Vigna unguiculata*) pastes and end product (akara) quality. *Journal of Food Science*, 67 (1), 48-52.

Kethireddipalli, P., Hung, Y-C., McWatters, K. H., & Phillips, R. D. (2002b). Evaluating the role of cell wall material and soluble protein in the functionality of cowpea (*Vigna unguiculata*) pastes. *Journal of Food Science*, 67 (1), 53-59.

Marsili, R. (1993). Protein Power: Functionality and versatility. Food Product Design. Retrieved May 23, 2005 from the World Wide Web October 28, 2004. www.foodproductdesign.com/archive/1993/0993ap2.html

McWatters, K. H. (1983). Compositional, physical and sensory characteristics of *akara* processed from cowpea paste and Nigerian cowpea flour. *Cereal Chemistry*, *60* (5), 333-336.

McWatters, K. H., & Brantley, B. B. (1982). Characteristics of akara prepared from cowpea paste and meal. *Food Technology*, *36*, 66-68.

McWatters, K. H., Chinnan, M. S., Hung, Y-C., & Branch, A. L. (1988). Effect of predecortication drying temperature on cowpea paste characteristics and functionality in preparation of akara. *Cereal Chemistry*, 65 (1), 23-27.

McWatters, K. H., Hung, C-Y. T., Hung, Y-C., & Chinnan, M. S. (2001). Akara-making characteristics of five U.S. varieties of cowpeas (*Vigna unguiculata*). *Journal of Food Quality*, *24*, 53-65.

Nagmani, B., & Prakash, J. (1997). Functional properties of thermally treated legume flours. *International Journal of Food Science and Nutrition*, 48, 205-214.

Ngoddy, P. O., Enwere, N. J., & Onuorah, V. I. (1986). Cowpea flour performance in akara and moin-moin preparations. *Tropical Science*, *26*, 101-119.

Patterson, S. P., McWatters, K. H., Hung, Y-C., Chinnan, M. S., & Phillips, R. D. (2002). Physico-chemical properties and consumer acceptability of akara (fried paste) made from three cowpea cultivars. *Food Research International*, *35*, 691-696.

Phillips, R. D. (1993). Starchy legumes in human nutrition, health and culture. *Plant Food for Human Nutrition, 44*, 195-211.

Phillips, R. D., Chinnan, M. S., Branch, A. L., Miller, J., & McWatters, K. H. (1988). Effects of pretreatment on functional and nutritional properties of cowpea meal. *Journal of Food Science*, *53* (3), 805-809.

Phillips, R. D., & McWatters, K. H. (1991). Contribution of cowpeas to nutrition and health. *Food Technology*, 45 (9), 127-130.

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L. R., & Phillips, R. D. (1996). Cowpea flour: A potential ingredient in food products. *Critical Reviews in Food Science and Nutrition*, *36* (5), 413-436.

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J-F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *Lebensmittel-Wissenschaft und-Technologie*, *33* (2), 72-79.

Scanlon, M. G., & Zghal, M. C. (2001). Bread properties and crumb structure. *Food Research International*, *34* (10), 841-864.

Singh, A., Hung, Y-C., Phillips, R. D., Chinnan, M. S., & McWatters, K. H. (2004). Particle-size distribution of cowpea flours affects quality of akara (fried cowpea paste). *Journal of Food Science*, 69 (7), 243-249.

Uzogara, S. G., & Ofuya, Z. M. (1992). Processing and utilization of cowpeas in developing countries: a review. *Journal of Food Processing and Preservation*, *16*, 105-147.

Vanchina, M. A., Chinnan, M. S., & McWatters, K. H. (2005). Manipulation of processing variables for improved functionality of cowpea (*Vigna unguiculata*) meal for use in making akara (fried cowpea paste). *Food Research International*, (Forthcoming).

SECTION V

SUMMARY AND CONCLUSIONS

Throughout the past research, there is evidence of the importance of maintaining protein conformation, having proper particle size distribution and the presence of cell wall material after milling in order to produce a dry cowpea meal acceptable for use in making akara. However, these factors had been examined without control of the other factors' influence. Continued research was necessary to identify whether one of the three mentioned factors is predominately responsible for proper functionality of cowpea paste and hence acceptable akara. Therefore, the objective of this work was to determine the importance of thermal abuse, particle size distribution, and wet versus dry milling in the processing of dry cowpea meal. This was accomplished by isolating the influence of the factors using different processing methods and formulating the meals to have known particle size distributions. The resulting meals were then evaluated to measure functionality of the paste and acceptance of akara made using the treatment meals.

Freeze drying was selected as a technology that allowed for processing of a meal that was wet milled and dried without application of heat. Due to the low temperature and absence of oxygen during the freeze drying process, degradation of components of the cowpea was minimized allowing the chemical, biological, physical, and organoleptic attributes to remain similar to those found in the unprocessed product. A hammer mill was used to dry mill cowpeas. Both meals were processed from undecorticated California Cream cowpeas.

Freeze dried cowpea paste was milled into a fine flour which could not be used to prepare akara as it did not foam (11.2% reduction in specific gravity after whipping) and produced a paste too fluid to be dispensed into frying oil. The meal processed from plate milling freeze dried paste also performed relatively poorly resulting in a paste with a

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chunky texture and only a 19.7% reduction in specific gravity after whipping. Therefore, it was concluded that wet milling alone was not sufficient to ensure good functionality of cowpea flour or meal and that particle size distribution was crucial.

The freeze dried and hammer milled meals were fractionated via sieving and recombined in a series of particle size blends all of which contained a minimum of 65% medium sized particles (0.180 - 0.425 mm) by weight with the remaining 35% made up of various combinations of large (0.425 - 1.000 mm) and fine (0.045 - 0.180 mm)particles. Indirect quality measures of paste and akara processed from the various blends (i.e. specific gravity and viscosity of paste and texture analysis of akara) indicated that there was one particle size blend that outperformed the others in both the hammer milled and freeze dried samples. The particle size distribution of the superior blend was 65% medium particles and 35% large particles. In the case of the freeze dried sample, the large portion consisted of 3 subfractions of equal proportion to mirror the particle size distribution seen in the hammer milled large fraction; these subfractions were: 0.850 – 1.000 mm, 0.600 - 0.850 mm, 0.425 - 0.600 mm. For the two 65% medium and 35% large particle meals, the specific gravity and viscosity values were significantly different from traditionally wet milled paste; however, the differences did not result in adverse paste handling characteristics. In addition, the hardness values of akara prepared from these two specific meals were not significantly different from the value for the traditionally prepared akara (5.317 N, 4.048 N, and 5.341 N respectively).

The two meals identified as having the best functionality (hammer milled and freeze dried meals consisting of 65% medium and 35% large particles) were further studied to determine if they produced akara of good quality that was acceptable to

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consumers. Measurements of particle size distribution of paste during the production of akara showed that the mean volume particle diameters of pastes made from the meals were not significantly different from the mean volume particle diameter of paste made from traditionally wet milled paste after blending (WTM: 246.60 µm, s.d.: 20.71, hammer milled: 218.02 µm, s.d.: 33.39, and freeze dried: 200.25 µm, s.d.: 6.182) or after whipping (WTM: 187.75 µm, s.d.: 5.19, hammer milled: 196.89 µm, s.d.: 11.93, and freeze dried: 190.79 µm, s.d.: 15.15). SEM micrographs of akara made from all three pastes showed crumb structure that was visually indistinguishable among samples. Quantifying the amount of air present in the sample by converting the SEM images to threshold images and using image analysis software demonstrated that there was no significant difference in the amounts of air in the three samples. No significant differences were found in sensory ratings, and the panel rated all attributes (appearance, color, aroma, flavor, texture) of the three akara samples above 6 (like slightly). The overall liking ratings of the three samples were also all above 6, and were not significantly different.

Results from this study show that the functionality of dry cowpea meal is mill independent as long as particle size distribution is controlled for. Regardless of whether wet or dry milling was employed, functional dry cowpea meal was processed under conditions that excluded thermal abuse as long as particles size distribution was 65% particles in the range of 0.180 - 0.425 mm and 35% in the range of 0.425 - 1.000 mm. Both the hammer milled and the freeze dried meals processed for this study served the purpose of shortening the time required to prepare akara and lessened the labor required; however, the freeze drying process consumed more resources (i.e. time and energy input)

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than the hammer milling process yet did not ultimately yield paste and akara that was significantly higher quality than paste and akara from either the traditional wet mill process or from hammer milled meal. For these reasons, it is evident that the benefits of freeze drying cowpea meal do not outweigh the costs. Hammer milling dry cowpeas and controlling for particle size distribution with 65% of the meal particles in the range of 0.180 - 0.425 mm and 35% of the meal particles in the range of 0.425 - 1.000 mm produced a dry cowpea meal that can be used for making acceptable akara very comparable to traditionally prepared akara.