DEVELOPMENT, PHYSICAL, AND SENSORY CHARACTERIZATION OF EXTRUDED, INDIRECTLY PUFFED PEANUT-BASED SNACK PRODUCTS

by

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(Under the direction of ROBERT D. PHILLIPS)

ABSTRACT

The goal of this research was to develop peanut-based snack products, known as third-generation snacks, using an extrusion process. Indirectly puffed extrudates were produced with a mixture of partially defatted peanut flour (12% fat) and rice flour using a co-rotating twin-screw extruder. The temperature profiles were 100, 120, 110, 95, and 80 ºC to prevent puffing of extrudates from feed zone to die, respectively. The extrudates were dried to obtain half-products (11-12% moisture). The half-products were expanded by deep-fat frying at 200 ºC for 35-40 sec. The quality of peanut-based snack products was determined by sensory evaluation, physical properties, cellular structure, and acoustic signal analysis.

A consumer acceptance test was conducted to determine the overall liking of snack products, and the optimum regions were identified using RSM. The Quantitative Descriptive Analysis (QDA) procedure was used to determine the characteristic sensory profiles of peanut-based snack products. The physical properties of snack products were significantly affected by peanut flour (30, 40, and 50%) followed by feed rate (4, 5, and 6 kg/hr) and screw speed (200, 300, and 400 rpm). Increasing peanut flour and feed rate resulted in lower degree of gelatinization and volume expansion ratio with higher bulk density. Response Surface Methodology (RSM) was used to determine the optimum area of formulations and extrusion conditions. Scanning Electron Microscopy (SEM) indicated that less expanded snack products have smaller cell size and thicker cell walls. The frequency ranges of acoustical signals produced by crushing snack products were identified from 4.5 kHz to 8.5 kHz by Fast Fourier Transformation (FFT). The lower peanut flour (30%) products produced more acoustic energy compared to the higher peanut flour (50%). The mechanical analysis revealed that the 30% peanut flour snack products were mechanically weaker than 50% peanut flour products.

INDEX WORDS: Extrusion, Snack, Peanut flour, Rice flour, Half-products, Consumer acceptance, Quantitative Descriptive Analysis Gelatinization, Bulk density, Volume expansion ratio, Response Surface Methodology (RSM), Cellular structure, Scanning Electron Microscopy (SEM), Acoustic signal, Frequency, Mechanical force, Mechanical energy,

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This dissertation is dedicated to

my parents

Myung-sook and Kyung-joo Choi

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INTRODUCTION

Snack foods have become an established part of our life style. In 1984, snack foods accounted for only 17% of total calories, but that number is expected to rise to 32% by 2005. People are consuming more snacks as meals, and more meals are snacks so that new snack food compositions are designed to be balanced meals (Wikes, 2000; Shukla, 2000).

Extrusion processing has become the standard operating system in most snack food industries. The main advantages of extrusion cooking are its energy efficiency, the lack of process effluents, and its versatility with respect to ingredient selection and the shapes and textures of products that can be produced (Harper, 1981). The evolution of snack foods has been classified as the first, second, and third generation snacks. Third-generation snacks are indirectly, expanded snacks made by extrusion processing followed by additional puffing steps by deep-fat frying or hot air stream to achieve the final texture (Moore, 1994).

Several different raw materials may be used in a formulation suitable for third-generation snacks. Materials include a variety of starches to create a soft and light texture. In addition, many types of proteins may be added to third-generation snack formulations, such as meats, dairy products, oil seed, and legume proteins to increase its nutritional quality. Peanuts are probably the most versatile food ingredient in the world, and have been extruded successfully to produce meat-like texture extenders and snack type foods (Ayres et al., 1974; Aguilera et al., 1980). They are also a good source of protein and amino acids, and can be used to supplement starch-based snacks to improve the nutritional quality (Woodroof, 1983).

Crispy food products have increased their impact in the food market as they provide energy, comfort, and pleasure to consumers in the last two to three decades, and they are still expected for a large development in coming years (Bouvier et al., 1997). Texture has been found to be one of the most important sensory acceptability descriptors to qualify crispy products. Food texture can be measured instrumentally in accordance with the science of rheology or subjectively by sensory evaluations (Bourne, 1982). The texture attributes of crispness and crunchiness are related to the cellular structure of crispy products. The cellular structure together with cell wall characteristics may determine both the physical properties, such as the acoustical and mechanical properties, and the sensory evaluation of the crispy products.

In the first phase of this study the peanut-based extruded snack products were evaluated among the target population to determine if they were of acceptable sensory quality. A consumer acceptance test of the peanut-based snack product was conducted to measure overall liking of snack product, and consumer-based optimization was performed using Response Surface Methodology (RSM). Quantitative Descriptive Analysis (QDA) was conducted to characterize the sensory profiles of snack products.

In the second phase, the physical properties of the expanded snack products were measured to characterize the effects of formulation and extrusion processing conditions. The material formulations and extrusion conditions were optimized based on the physical properties using Response Surface Methodology (RSM).

The third phase of this study involved the analysis of cellular structure of peanut-based extruded snack products. Scanning Electron Microscopy (SEM) was used to analyze the internal geometrical structure of snack products, such as cell size distribution

Finally, the crispness of expanded snack products was characterized by analyzing the acoustical signals and mechanical force-deformation curves generated by compressing the snack products using Instron Universal Testing Machine. The frequencies and acoustical energy were identified using a Fast Fourier Transformation (FFT).

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SECTION I

LITERATURE REVIEW

I. SNACKS

According to a recent public opinion survey conducted by Tupperware Corporation (Orlando, FL), nearly three-quarters (73%) of 1,017 adults reported snacking at least once a day, and almost 40% reported snacking more than twice a day. Nearly a quarter (23%) of those surveyed said they snack a few times a week or less, and only 4% said they never snack at all. The Tupperware poll revealed Americans were trying to make healthy snacking choices. The fact that some chose fresh fruits or vegetables as their favorite snack was interpreted as a healthy sign. However, only 30% selected fresh fruits and vegetables as their favorite snack, which means that 70% had another favorite, such as chips, cookies, pastries, or candies (Jones, 2000). A 1998 Gallup Study of American Snacking Behaviors found that the most common motivations for snacking are to satisfy hunger between meals and to satisfy one's sweet tooth, and convenience is the second most important factor affecting consumer snacking purchases. In 1984, snacking accounted for only 17% of total calories, but that number is expected to rise to 32% by 2005. Snacking has become an established part of our lifestyle. More than 30% of the calories Americans consume today are in the form of snacks, and generally, snacking now provides approximately 30% of many American's daily calories. People are consuming more snacks as meals, and more meals are snacks so that the distinction between snacks and meals are blurred (Wikes, 2000). Everybody has different criteria for the work snack: a snack should provide quick energy; a snack should be easy to eat; a snack should taste great.

An examination of the last 10 years of savory snack foods patented technology reveals a number of trends in terms of new ingredients, processes, and product attribute.

Modern snacks are no longer a 50/50 blend of fats and carbohydrates. In some cases, fat content has decreased to less than 10% and dietary fiber and protein levels have increased to 12-15 and 22-30%, respectively. Many modern snacks are fortified with minerals, vitamins, and functional food ingredients, such as natural antioxidants. In essence, new snack food compositions are designed to be balanced meals on the go (Shukla, 2000). The snack food marketplace is undergoing unprecedented revolution. There are basic changes in what consumers want from snacks, and how they want these benefits delivered. Key examples include the synthesizing and intertwining of "taste" and "health"(what consumers want) and "sweet" and "salty" (how they want it delivered). The key snacking trends identified revolves around the healthfulness, textural blending, sensory fulfillment, increased involvement, and snack/meal blending (Posten, 1996).

Classification of Snacks

The evolution of snack foods has been described with certain types of snacks being associated with a specific generation of products. The first generation snacks are considered conventional potato chips and baked crackers. Second generation snacks encompass the puffed collets produced by a low moisture extrusion processing (<15%), where the major sources used to produce highly expanded collets are degerminated corn grits, other cereals, and/or starch. Once extruded, the collets are dried (or baked in the industrial vernacular) to lower than 4%, and can be coated with flavors and oil (Sunderland, 1996; Harper, 1981). Third-generation snacks are indirectly expanded snacks, referred to as half-, semi-, or intermediate products. Products in this category can involve a variety of shapes and textures that are not possible with collet extrusion technology. During extrusion processing for half-products, the end zone of the barrel in an extruder operates a relatively cool temperature, below the boiling point of water, so that the shaped product will be precisely formed before cutting. There are additional process steps, which contribute to the appearance and texture. The additional process steps typically include a frying or hot air puffing step to remove moisture and achieve the final texture (Moore, 1994).

Processing Steps of Third-generation Snacks

There are different steps in producing third-generation snacks by extrusion processing, which has become the standard operating system in most snack food industries (Harper, 1981). Twin-screw technology enables the process of cooking and forming to be carried out in one extruder. The ingredients are properly blended (may be mixed with liquids, flavors, colors, and vapors prior to extrusion), and then gravimetrically conveyed to the extruder barrel (Sunderland, 1996). The extruder transforms the raw materials to fully cooked and shaped products by providing thermal and shear energy to the food material resulting in significant physical and chemical changes. Specifically-designed screws can be used to convey and knead materials, create back-flow, input high mechanical energy and turbulence, and increase or decrease residence time (Harper, 1981). During the extrusion, the starch portion of the formulation must be completely cooked or gelatinized for desirable texture to be achieved after puffing. A complete cook is achieved through the correct combination of temperature, moisture, and residence time in the extruder. The processing conditions in the extruder may vary depending on the type and amount of starches used in the materials. Ordinarily, temperature in the cooking zone of the extruder will range from 80 to 150ºC and 65 to 90ºC in the forming zone. The moistures will range from 25 to 30%

moisture content, with a residence time of 30-60 sec. After the cooking step, the material may be transported to a venting zone, which serves to cool the cooked mass. The extrudate is then moved along to the forming zone of the extrusion system where cooling is maximized to reduce product temperatures to 70-95ºC (Sunderland, 1996). The shaping of the dough at low temperature prevents the puffing forces of water turning to steam (Moore, 1994). As the extudate exits the die, a proper die cutting devices may be used to produce three-dimensional shapes or a continuous sheet. The formed pellets, now containing 20-28% moisture, are ready for the drying step. Drying is very critical in the production of good quality third-generation snacks. Adequately dried pellets of 10-12% moisture are now suitable for the additional processing steps, which typically include a frying or hot air puffing step to remove moisture and achieve the final texture. In this state, the pellets can be held for long periods, shipped long distances, and distributed to small snack food manufacturers or directly to consumers. Traditionally, the pellets have been expanded by deep-fat frying or a hot air stream, and can be sprayed with an oil-based savory seasoning coating. Popular low-fat snacks now utilize hot air and microwave systems for expansion (Sunderland, 1996).

Several different raw materials may be used in a formulation suitable for third-generation snacks. Generally speaking, total starch levels of 60% or less in a formulation will give only slight expansion and will yield a final product with a hard and crunchy texture after frying. Conversely, as the total starch level exceeds 60%, the final product will expand more, resulting in a slight, “frothy” texture. Pellet ingredients include food starch, wheat flour, rice flour, corn, modified food starch, and potato solids for typical formulations for third-generation snack products to create a soft and light texture. In addition, many types of proteins may be added to third-generation snack formulations, such as meats (fresh shrimp, fish, chicken, beef, etc.), dairy products (cheese, yogurt, milk solids), oil seed and legume proteins (peanut, soy, pea, bean), at levels of up to 30-35% and still maintain high-quality final products (Sunderland, 1996; Swientek, 1987).

Crispness of Snack Foods

In the last two to three decades, crispy food products have increased tremendously their impact in the food market, and all market analysts are still expecting a large development of such products in the coming years. As a matter of fact, potato chips, crispy bread, snacks, and breakfast cereals today lead the market of crispy products as they provide simultaneously energy, comfort, and pleasure to consumers (Bouvier et al., 1997). In general, crispness can be defined a highly valued and universally linked textural characteristics that have many positive connotations (Szczesniak and Kahn, 1971). Amerine et al. (1965) defined crispness as a textural property characterized by a brittle, friable nature. Bourne (1975) indicated that a crisp or crunchy food is characterized by having a rigid, non-deformable, stiff structure that suddenly collapses with a brittle fracture and a rapid decay of the force after fracture. These foods have very low shear strength, break up under simple compression between the teeth with little or no grinding or tearing, and rapidly break down into small pieces with low work required for mastication. Vickers and Bourne (1976) proposed that crispness is primarily an acoustical sensation. They reported that a crisp food produces a characteristic sound when it is bitten or crushed. This sound may be described as having a broad range of frequencies with no particular one predominating, and irregular or uneven variations in loudness. They also described the relationship between cellular structure and sound effects. As a crisp cellular structure is crushed, it produces a series of sounds: each sound is generated by the rupturing of a single cell. The collective rupturing of many cells over the duration of a bite or crushing produces the characteristic sound. The amplitude of the crisp sound at any instant is the product of the loudness of the sound produced by an individual cell and the number of cells rupturing. Vickers (1984) also observed that the sensations of crispness and crunchiness might differ in pitch, and found that the more crisp foods nearly always produced higher pitch sounds than the more crunchy foods. Seymour and Hamann (1988) reported that the definitions of crispness and crunchiness were based upon the physiological manipulation and sound; that is, crispness was evaluated by placing a sample between the incisors and detecting a level of high pitched sound, meanwhile, crunchiness was evaluated by placing a sample between molars and detecting a low pitched sound. They also found that crunchiness in a product tended to be at lower frequency than a crispy product.

Snack materials have a low water content, which provides stability and retention of desired textural properties. Exposures of such food materials to high relative humidity (RH) often result in water sorption and a detrimental increase in water content (Roos et al., 1998). Katz and Labuza (1981) showed that some snack foods lost their crispness when stored at a RH higher than a material-dependent critical value. Loss of crispness in low-moisture food materials, as a result of water plasticization, can be considered as a collapse phenomenon, which is often governed by glass transition (Tg) (Levine and Slade, 1988). Glass transition refers to the change in the physical state between the super-cooled liquid and solid, glassy states of amorphous materials. Crispness is associated with the glassy state, and the change from crispy (brittle, noisy) to deformable (ductile, silent) was thus attributed to the glass transition of the product (Slade and Levine, 1993). Attenburrow and Davies (1993) pointed out that a number of cereal-based foods are intended to be consumed when the materials are in the glassy state. However, the water content which is sufficient to depress the glass transition to below room temperature is highly dependent on material composition and, therefore, differences in the critical water activity (Aw) or water content values of various food materials are expected (Roos, 1993).

Characterization of Crispness

Several researchers agree that crispness should result from the structural properties of a food (Bouvier et al., 1997; Barrett et al., 1994; Mohammed et al., 1982). Crispness is perceived to be related to the cellular structure of foods, and the product's cellular structure and geometrical properties is likely to be the most direct method for crispness measurement (Gao and Tan, 1996a). Mechanical properties may be one of objective measurements for crispness. Mechanical properties are believed to reveal the structural properties of materials by means of the resistance to a compression of blade/probe and to a tension that pulls apart the structure of a food material (Bourn, 1982). The breakdown of structure may generate small and numerous pieces, associated with sound effects. Pioneering work on acoustic properties conducted by Drake (1963) revealed that sounds from crispy foods differ from non-crispy foods in loudness. Due to the fact that the crushing of crispy or crunchy foods results in fracture and fragmentation, it appears that fracture and sound emission are associated (Tahnpoonsuk, 1999). Perhaps the sound burst during compressing or biting snack-like foods might be used to predict the structure and mechanical properties of crispy products.

II. EXTRUSION PROCESSING

The first cooking extruder was developed in the late 1940s, and this led to a great expansion in the application of extruders for food production. “cooking extrusion” generally means the combination of heating food products with extrusion to create a cooked and shaped food product. Raw materials, such as starches, flour, and proteins, are cooked and worked into viscous plastic-like dough. Heat is applied directly by electric heaters or mechanical shear. Process temperatures can reach 200ºC, but the residence time is generally short, which may be 10-60sec. This type of extrusion is known as high temperature, short time (HTST) process. Heating ingredients quickly at high temperatures improves digestibility and minimizes detrimental effects, such as browning and production of off-flavors. Cooking extruders allow a wide range of moisture contents (10-40%), feed ingredients, cooking temperature (110-200ºC), and residence times. In addition, the ability to vary the screw, barrel, and die configurations makes the cooking extruder highly versatile (Schuler, 1986). The food extruder has been described as a continuous-flow reactor capable of processing bio-polymers and ingredient mixes at relatively high- temperature under high pressures and shear forces at relatively low moisture contents. The extrusion cooking of food causes a series of chemical and physical changes occurring because of heating and shearing during the time of passage through the extruder. These changes encompass protein denaturation and cross-linking, starch gelatinization and dextrization, browning, denaturation of vitamins and enzymes, etc., and are obviously very complex. The resulting properties of the cooked food are a composite of all components, which emerge from the extruder die (Harper, 1981). The properties of extrudates during extrusion process are influenced by the machine variables (e.g., barrel, screw, and die design), the extrusion variables (e.g., barrel temperature, screw speed, screw configuration, and feed rate), and the feed composition variables (e.g., protein, starch, fiber, water, lipid, sugar, and salt contents). The interaction among all these variables transforms the feed materials leading to the changes in product qualities (Colonna et al., 1989; Phillips, 1989). To date, extrusion is used in the production of such diverse products as pasta, breakfast cereals, bread crumbs, biscuits, crackers, crispbreads, croutons, baby foods, chewing gum, texturized vegetable proteins, modified starches, pet foods, dried soups, and dry beverage mixes (Linko et al., 1983). Extrusion processing has become the standard operating system in most snack food industries throughout the world.

A. Extruder

Extruders can be categorized into one of three main types: piston extruders, roller extruders, and screw extruders. Screw extruders, the third category, are usually classified by how much mechanical energy they can generate. A low-shear extruder minimizes mechanical energy, and is used to make pretzels, pasta, some types of snacks, and some breakfast cereals. Whereas, a high-shear extruder imparts a high level of mechanical energy to make puffed snack foods, other breakfast cereals, and pet foods (Frame, 1994). Screw extruders employ single, twin, or multiple screws rotating within a stationary barrel to push the material forward and through a specially designed orifice, called a die (Dziezak, 1989).

Single-screw extruder: Single-screw extruders consist of three sections: feed, transition, and metering. The extrusion screw sequentially conveys and heats food ingredients through frictions, and works them into a continuous plasticized mass while rotating in a tightly fitting barrel. The screw can be designed either as a single piece or as a splined shaft that accepts screw sections of varying configurations to increase versatility and reduce the cost of replacing worn sections (Harper, 1989). Single-screw extruders are mechanically simpler, easier to operate, and less expensive than twin-screw extruders (Harper, 1989; Starer, 1996). However, the application of single-screw extruder is limited. As single-screw extruder relies on drag flow to move material down the barrel and develop pressure at the die, single-screw extruder has the trouble conveying low-viscosity materials. Dough that is conveyed must be relatively viscous to reduce the product sticking to the walls of the extruder's barrel (Demetrakakes, 1997; Starer, 1996; Frame, 1994). A single-screw extruder is relatively ineffective in transferring heat from barrel jackets because convective heat transfer is limited by poor mixing within the channel. Instead, the jackets in single-screw extruders control barrel wall temperature to regulate slip between the food ingredients and the wall (Harper, 1989)

Twin-screw extruder: Twin-screw extruders are considerably more complex than single-screw extruders, but they provide much better conveying and mixing feed materials, control of residence time, and internal shear of food ingredients (Harper, 1989; Demetrakakes, 1997). Twin-screw extruders were characterized according to their various types of screw configurations. The relative direction of rotation of the screws, counter-rotating (rotate in opposing directions) or co-rotating (rotate in the same directions), and degree of screw intermeshing are key points of differentiation. Both counter- and co-rotating screws clean themselves. These self-wiping screws are desirable and often necessary to prevent material from adhering to the screw root (Schuler, 1986). Co-rotating twin-screw extruders have become popular in food processing because of their high capacity and enhanced mixing capacity: their greater conveying angle and self-wiping features make it possible to handle a wider variety of ingredients. Improved processing also occurs because of the uniformity of shear rate across the channel depth on twin-screw extruders, the narrower residence time distribution (RTD), and increased mixing in the screw channel. However, twin-screw extruders have torque, pressure, and thrust limitations, which are necessary to prevent extensive damage and expensive repairs to the drive train (Harper, 1989). The co-rotating twin-screw extruder is a drag flow device like a single-screw extruder. However, the potential for the product to rotate within the screw at its rotational velocity is impeded by the flight of the other screw resulted in changing its direction (Frame, 1994). An important characteristics of screw type is its influence on the shear stress distribution across and along the screw channel. Co-rotating screws under the same parameters have lower stresses at the barrel walls and much more uniform stress distribution in the screw channel. This uniformity of stress is beneficial in mixing efficiency and from an energy standpoint (Schuler, 1986). In general co-rotating twin-screw extruders offer the most flexibility for producing a wide variety of food products (Frame, 1994).

B. Effects of Extrusion Variables on Extrusion Process

Specific Mechanical Energy (SME): There are two sources of energy input to the extruder. One is the mechanical dissipation of the motor power through shear and interparticulate friction in the extruder channel. This is the dominant source of energy during the processing of low moisture, highly viscous materials at high screw speed (Chiruvella et al., 1996). The other source of energy is the electrical heat input transferred through the barrel wall. Under the low viscosity conditions with decreasing mechanical energy requirements, electrical heat energy input through the barrel becomes necessary for material transformation (Bhattacharya and Hanna, 1987). The energy input by the extruder in transforming the material is measured by the specific mechanical energy (SME). This is a system parameter, defined as the energy provided by the motor drive to the material in the extruder per unit mass (J/kg). It reflects the extent of thermo-mechanical cooking in the extruder and it is influenced by the moisture content, barrel temperature, screw speed, and throughput (Janssen, 1989).

Screw Configuration: The conveying screws generate the pressure necessary for the material to flow through the mixing restrictions. The degree of barrel fill can be indicated by information such as torque and pressure differentials (Frame, 1994). Mechanical energy that is not used for moving the dough down the extruder barrel is dissipated in it as heat and shear energy. One of the ways to increase the amount of mechanical energy input into the dough is to include in the screw configuration, elements that interfere with transport. These include mixing paddles, reverse screw elements, cut flights, and orifice plugs (Harper, 1989).

Screw Speed: Screw speed is one of the factors in the extrusion process that affects the degree of barrel fill, residence time, and the shear stress on the extruded materials (Colonna et al., 1989; Frame, 1994). An increase in screw speed causes increased shear rate, increased potential for mechanical damage to the food molecules (Harper, 1986), decreased degree of barrel fill, and decreased residence time (Colonna et al., 1989: Frame, 1994). The measured torque and die pressure changes with screw speed: as the screw speed increases, the value of torque is reduced because the degree of barrel fill becomes less. The viscosity of the material may also be reduced because of the increased shear (Frame, 1994). High shear rate at the die increases damage to the materials and reduces starch molecular size resulting in small pore extrudates, high solubility, and low mechanical strength (Harper, 1986).

Residence Time: Residence time determines the extent of chemical reactions and ultimately the quality of the extrudate. It is also useful for scale-up and for verifying prediction of extrusion models. Meuser et al. (1992), in a system analysis of the extrusion process, considered residence time as a system parameter that is the link between process variables (screw speed, mass flow, and moisture content) and product parameters (texture, taste, and other indices of material transformation). Gogoi and Yam (1994) suggested that while it is useful to be able to manipulate the process variables to produce a desirable product quality attribute, it is more practical to take a two-step approach. They proposed to relate process variables with system parameters, and then in a second step to relate system parameters with quality attributes of the extrudates. Accordingly they determined that increasing mass flow rate (a processing parameter) decreased the specific mechnical energy (SME), the mean residence time, and the spread of the residence time distribution (RTD).

Temperature: Barrel temperature profile is one of the important factors, which influence the quality of extrudates. For direct-expanded products, the temperature of barrel near the die must be carried out at temperature above 100ºC to allow water evaporation into steam resulting in expansion of the starch matrix during exiting the die. For half-products, after doughs are cooked in the extruder, they are forced through the die at a temperature below 100ºC to prevent puffing (Moor, 1994). High temperatures increase product temperature resulting in a decrease in the dough viscosity and pressure in the die, and also affects the properties of extrudates by providing a highly expanded products with large internal cell structures that are easy to break (Colonna et al., 1989; Lawton et al., 1985). Frame (1994) stated that a decrease in temperature during the extrusion process could be caused by increasing water or oil content (function of lubricant), reducing screw speed, or reducing the severity of the screw configuration.

Pressure: Pressure can be measured to infer the viscosity or consistency of the food material before it flows through the die. Material viscosity can be correlated to finished product characteristics and therefore serves as an important control variable for the extrusion process. Pressure changes behind the die can serve as an indicator of extrusion operations. Rapidly changing pressure signals surging and all of the detrimental consequences of that phenomenon (Harper, 1989). Levine et al. (1987) further postulated that the rate of change of pressure is an extremely rapid indicator of fluctuations in the moisture content or ingredient characteristics of the feed.

C. Nutritional and Chemical Modification during Extrusion

Starch

Starch is a carbohydrate found in plants in the form of granules. Starch consists of two main polysaccharides, amylose and amylopectin. Both polysaccharides are based on chains of 1→ 4 linked α-D-glucose, but whereas amylose is essentially linear, amylopectin is highly branched containing on average one 1→6 branch point for every 20-25 straight chain residues (Hoseney, 1994). Starches can be classified into three groups. The first group is composed of tuber (potato), root (tapioca, arrow root, and sweet potato), and pith (sago) starches. The second group includes cereal starches (corn, wheat, sorghum, and rice). The third group comprises the waxy starches (waxy maize, waxy sorghum, and waxy rice) obtained from cereals, but having physical properties similar to those of the root starches (Swinkels, 1985). Starches from different plant sources consist of different ratios of amylose to amylopectin (Pomeranz, 1991). In normal cereals, the amylose content is about 23 ± 3% (Hoseney, 1994). Starch occurs naturally as water-insoluble granules, and when viewed under polarized light the granules are birefringence, and also partially crystalline with crystallinities in the region of 30%.

Starch gelatinization: Starch is usually processed by heating in the presence of water, which disrupts the native crystalline structure, a phenomenon known as gelatinization. One of the essential elements of the gelatinization process is the loss of crystalline order. Starch granules undergo gelatinization by the action of heat and moisture of extrusion processing on hydrogen bonding, lose their native crystalline order, which undergo melting and chain mobilization, and swell irreversibly. Swelling of the granule upon gelatinization clearly has a major impact on the rheology of starch pastes, and further opening of the granule structure to the action of water occurs (Parker and Ring, 2001; Donovan, 1979).

Starch Expansion: Extrusion cooking technology has been applied extensively in manufacturing cereal or starch-based crispy foods. The texture and mouth-feel of most expanded or puffed, extruded snacks depend on their expansion volume (Owusu-Ansah et al., 1983). In extrusion processing, “expansion” is used to describe the events that lead to the formation of puffed, low-density cellular materials from a hot, gelatinized mass of starch, which is forced under pressure through a restricted opening into the atmosphere. Formation of acceptable expanded products of a desirable shape and texture is dependent on a number of factors. The most important contributors to good expansion include adequate gelatinization of the starch, development of sufficiently large pressure drops at the orifice to cause rapid boil-off of water vapor, and formation of a strong cellular structure and skin due to rapid evaporative cooling (Camire *et al*., 1990). Several studies indicated that the qualities of raw materials such as contents of protein, lipid and starch and their composition and type are important in controlling expansion volume (Launay and Lisch, 1983; Mohamed, 1990).

Chinnaswamy and Hanna (1998a,b) observed that the compositions of starch, amylose and amylopectin seem to influence expansion volume. Chinnaswamy (1993) extruded cornstarches under the optimal conditions, and observed the relationship between expansion ratio and the amylose content of the native starches. The results clearly showed that the amylose content of starch could be a controlling factor for expansion ratio. Mercier et al. (1975) reported that waxy starch, which has very low levels of amylose, has superior expansion properties compared with other types of corn. The temperature and moisture content might play a greater role in changing the viscoelastic properties of the starches, which in turn affect the expansion volume (Kokini et al., 1992). Chinnaswamy (1993) reported that if there is a physical modification in the starches due to changes in barrel temperature and moisture content, it might help poorly expanding starch varieties to expand more. And also, to alter the raw material quality, chemical substances such as urea, which is a hydrogen bond breaking agent; sodium bicarbonate, which decomposes to carbon dioxide (increase pressure) at extrusion temperatures; and sodium chloride, a metallic salt known for its efficient heat conduction, were mixed starches before extrusion cooking.

Starch Degradation: The degradation of native starches at high temperatures, pressures, and shear rates has been applied to many materials, particularly in the production of high dextrose equivalent (DE) syrups and alcohol (Chouvel et al., 1983; Ben-Gera et al., 1983). Colonna et al. (1984) studied that a reduction in amylopectin molecular weight after extrusion at 11% moisture, screw speed of 270rpm, and both 130 and 180ºC. They assumed that shear might be a major factor for the loss of molecular weight. The degradation of starch can have profound effects on product sensory quality, extruder control, and nutritional value of starch produced through the process. Bjorch et al. (1984) found that both the in vitro and in vivo digestibility of extruded starch was enhanced by extrusion and that the degree to which this effect is produced is controlled by the severity of the extrusion process.

Protein

Maillard Reaction: The chemical reaction between a reducing sugar, such as glucose, fructose, or maltose, and a free amino group on an amino acid, usually the epsilon-amino group of lysine, has important nutritional and functional consequences known as non-enzymatic browning (Waller and Feather, 1983). During extrusion, starch and non-reducing sugars such as sucrose may be hydrolyzed during extrusion to form reducing sugars, which were proposed to be the cause of lysine loss by a Maillard reaction in extruded wheat flours (Bjorck et al., 1984). The Maillard reaction is favored by conditions of high temperature (>180ºC) and shear (>100 rpm) in combination with low moisture (<15%) (Cheftel, 1986). Pham and Rosario (1986) reported higher losses of available lysine in extruded legume flours when temperature was held constant and the water content of the mix was increased. However, available lysine was higher with increased screw speed, which decreased the residence time in the extruder. Increased feed rate significantly improved lysine retention in extruded wheat flours. Camire et al. (1990) reported that extrusion cooking appears to cause lysine losses that do not exceed those for other methods of food processing. Phillips (1988) has suggested that the Maillard reaction is most likely to occur in expanded snack foods in which nutritional quality is not a major factor and that breakfast cereals and other extruded foods with higher moisture contents will undergo much less available loss.

Cross-Linkages: Proteins processed under conditions of alkaline pH and heat may develop amino acid residues that are not found in nature, and this protein nutritive quality is reduced (Cheftel et al., 1985). Kinsella (1978) reported that since protein cross-links may develop between peptides or within a peptide, the resulting change in conformation may also affect the physical characteristics of the food containing them. However, they observed that extrusion-texturized soy proteins are less likely to develop cross-linked amino acids during the high temperature short time (HTST) extrusion conditions.

Protein Digestibility: The nutritive value of a protein is dependent upon the ease with which it can be digested as well as amino acid pattern. In general, heating improves the digestibility of proteins by inactivating enzyme inhibitions and denaturing the protein, which may expose new sites for enzyme attack. Increasing barrel temperature during extrusion has been shown to increase the digestibility of corn gluten-whey blends (Bhattacharya and Hanna, 1988), fish-wheat blends (Bhattacharya et al., 1988), and sorghum (Fapojuwo et al., 1987). Increased screw speed may have increased the protein digestibility of extruded corn gluten because the increase in shear forces in the extruder denatured the proteins more easily, thus facilitating enzyme hydrolysis (Bhattacharya and Hanna, 1988).

Protein Solubility: Denaturation is any change in the conformation of a protein that does not involve the breaking of peptide bonds. Typically, hydrophobic groups are uncovered during denaturation, resulting in decreased solubility of the protein in aqueous solutions (Cheftel et al., 1985). Factors that encourage protein denaturation, such as higher temperature and increased residence time, reduce solubility (Camire et al., 1990).

Texturization: One application of extruders is for texturization of defatted vegetable proteins (Cabrera et al., 1979). A meat-like texture is obtained and the products can be used as meat extenders (Bjorck and Asp, 1983). According to Cumming et al. (1973), during thermoplastic extrusion of soy protein the water-soluble protein breaks into subunits and becomes redistributed and/or insoluble. They interpreted the texturization as an effect of new hydrogen and disulphide bonds. This should not impair the susceptibility to enzymatic proteolysis.

Lipid

The class of chemical compounds known as lipids is a heterogeneous group of nonpolar materials including glycerides, phospholipids, sterols, and waxes. Triglycerides, which are the most common type of lipids occurring in foods, consists of three fatty acid molecules esterified to one glycerol molecule (Camire et al., 1990). Cereals such as wheat and corn are typically low (2%) in oils, although oats may contain up to 10% oil. Oilseeds such as peanut, cottonseed, and soybeans may contain up to 50% by total seed weight as oil. Free fatty acids causing rancidity are produced by the hydrolysis or lipolysis of triglycerides due to lipases, moisture, and heat. The inactivation of hydrolytic enzymes is possible with extrusion processing. Higher temperatures reduce the lipase activity and moisture level, thereby decreasing the factors favoring free fatty acid development. Sayre et al. (1985) reported that high moisture levels and enzyme activity rapidly deteriorate the food quality of rice bran, but even mild extrusion condition had favorable effects on the stability of rice bran stored for 6 weeks. Extrusion-inactivation of lipase and lipoxidase helps protect against oxidation during storage (Cheftel et al., 1985).

Nutritional Value: Since humans lack the ability to add double bonds beyond the ninth carbon of a fatty acid, the essential fatty acids-linoleic, linolenic, and arachidonic-must be supplied by the diet. Isomerization of the double bonds from the cis to the trans form destroys the essential activity of these polyunsaturated fatty acids (Camire et al., 1990). Maga (1978) found that only 1 to 2% of the unsaturated fatty acids was converted to the trans form during the extrusion of cornmeal.

Vitamins and Minerals

The retention of vitamins generally decreases with increasing temperature and/or residence time of the material in the extruder. Killeit (1994) investigated the stability of B-complex vitamins during the production of extruded flat bread. They suggested that with increasing throughput the retention of vitamins B_1, B_6, and B_{12} improved. They also reported that an increase of initial moisture content by adding 3-11% water improved retention of the vitamins and of folic acid. This effect can be explained by the fact that higher moisture leads to lower viscosity of the material. As a consequence the product is less sheared and the dissipative energy input drops. Extrusion cooking generally affects macromolecules more than small molecules. Smaller molecules may be impacted upon by either the extrusion process itself or by change in larger molecules, which in turn affect other compounds present in the food (Camire et al., 1990).

III. PEANUTS AND RICE

Peanuts

Peanuts consist of shells (Spanish about 20% and Runner 26%) and kernels (80% Spanish and 74% Runner). The kernels are made up of about 72.4% cotyledons (halves), 4.1% skins, and 3.3% germs (hearts). Peanut kernels are composed of approximately equal weights of fatty and nonfatty constituents, the relative amounts of each depending on variety and quality of the peanuts. Most of the fatty constituents are contained in the cotyledons, some are found in the germs or hearts, and small amounts are generally found in the skins (Woodroof, 1983). Peanuts (*Arachis hypogaea* L.) are characterized by high oil and protein contents and a low percentage of carbohydrates and ash. The oil from these seed is of high quality, and a large percentage of the world production of peanut is utilized as an edible oil source. In the USA, generally, about 60% of the production goes into domestic food use, the end products being peanut butter, salted products, confectionaries, and roasting stock (Ahmed and Young, 1982).

Changes occur in peanut kernels after harvest that affect texture, flavor, aroma, and color; and these, in turn, determine the usefulness of the peanuts in peanut products, such as peanut butter, snacks, bakery goods, and others. Most of the flavor of peanuts is in the oil, and partial or total removal of oil also removes flavor. Furthermore, most of the staleness and rancidity of peanuts occurs in the oil, and partial or total removal of oil renders them more stable. Arginine, an amino acid that causes peanuts to taste bitter, is present in immature peanuts but free amino acid disappears as peanuts mature. When peanuts are roasted, the sugars and free amino acids react to produce the typical roasted peanut color, flavor, and aroma. Proper handling during harvesting, curing, storing, and processing is important in giving a desirable quality (Woodroof, 1983). Peanuts are composed of relatively large quantities of protein (25-34%) and oil (44-56%) and have high energy value, which is average 564 calories/100g seed (Cobb et al., 1973).

Proteins: Crude protein of whole seed peanuts ranges between 22 and 30% (Altschul, 1964; Pancholy et al., 1978), and peanut meal has almost twice that amount (Woodroof, 1983). Total protein can be separated into albumin, and the globulin, arachin, nonarachin or conarachin (Cherry et al., 1973). Arachin represents about 63% of the total protein and rich in threonine and proline and poor in lysine and methionine, while conarachin fraction represents about 33% of the total protein and poor in lysine and methionine. The contents of amino acids in peanut seed vary according to type of peanuts, cultivar, location, years and during maturation of the seed (Kaneko et al., 1978). The greatest nutritional weakness in peanut protein is a low content of two amino acids essential to both human and animal nutrition, lysine and methionine (Woodroof, 1983).

Oils: Peanut seed may range in oil content from 44% to 56% with an average of 50%. Peanut oil is light yellow with a slightly nut-like flavor, and it is a low viscosity type fluid. Peanut oil is an unsaturated lipid and has small amounts of fatty acids with 10 carbons or less. Peanut oil contains about 80% unsaturated fatty acids with more oleic acid (47%) than linoleic acid (33.2%)(Cobb et al., 1973). Koman and Kotuc (1976) calculated the ratio of the sum of all polyunsaturated fatty acids to the sum of all saturated acids (P/S), which was considered as an indicator of oil stability. The P/S ratio for peanut oil was 1.8 as compared to 2.9 for soybean oil and 4.3 for corn oil. These oils contained more polyunsaturated fatty acids (principally linoleic acid) than peanut oil. The contents of linoleic acid and other polyunsaturates are inversely proportional to the keeping quality of oil. Accordingly, peanut oil has a better keeping quality than soybean, corn, and safflower oil.

Carbohydrates: The cotyledons of peanuts naturally contain about 18% carbohydrates and the skins about 1%. The starch content of peanuts varies from 0.5 to 5%, depending on the type, growing condition, and maturity. Starch content of peanut meal is 6.7%. Sucrose is reported to constitute 4-7% of peanuts. The browning reaction accounted for the principal changes occurring in color and flavor during peanut roasting, and sucrose is the leading carbohydrate involved (Woodroof, 1983).

Minerals and Vitamins: Peanuts contain about 3% ash, with about 4% in the meal. Of 26 inorganic constituents in peanut kernels, potassium, magnesium, phosphorus, and sulfur are high and virtually unaffected by heating. It is highly probable that peanuts are good source of other members of the B vitamin group, such as pyridoxin (vitamin B_6) and pantothenic acid: kernels are an excellent source of riboflavin, thiamine, and nicotinic acid. They also contain considerable amounts of vitamin E, but practically no vitamins A, C, or D. Appreciable amounts of B complex vitamins and vitamin K are likely present. (Woodroof, 1983). Vitamin E plays a role as an antioxidant and, therefore, prevents and/or delays lipid oxidation, including oxidation of low density lipoprotein (Esterbauer et al. 1991). Lee et al. (1998) extracted four tocopherols (α-T, β-T, γ-T, and δ-T) of vitamin E in the peanut and peanut butter using different extraction methods. They reported that γ-T was identified as the major homolog in peanuts. From a nutritional point of view, α-T has higher biological activity compared to the other three tocopherols, whereas from the stability point of view, the higher γ-T protects the stored fats acting a more effective in vitro antioxidant (Lavedrine et al. 1997).

Other components: There are other little known components in peanuts, which account for colors, aromas, flavors, and texture. The red skins, representing 2.0-3.5% of the kernels, contain tannins and related pigments, which cause undesirable color unless removed during initial processing. Red skins were found to contain about 7% tannin, 7.9μg/100g vitamin B or thiamine, and were rich in leucoanthocyanin. Typical peanut flavor, nuttiness, sweetness, and bitterness can be altered by variety, growing conditions, methods of harvesting, storing, and processing. Peanut flavor is closely related to the oil, and on separation the flavor goes with the oil rather than with the meal. In practically all cases of heating the flavor is accentuated (Woodroof, 1983). In addition, Peanuts have great potential in foods, as it has neither the objectionable beany flavor nor gas-producing compounds of some legumes

Peanut-Based Snacks: Ayres et al. (1977) reported that the addition of defatted peanut flour to corn curl formulations containing degerminated cornmeal and rice flour increased the protein content without adversely affecting bulk density and flavor; these snacks were processed by extrusion with partial steam cooking, drying, and deep-fat frying. Bongirwar et al. (1979) determined optimum conditions for extrusion cooking of peanut flour for production of high protein, ready-to-eat foods. They observed that free oil released from full-fat peanut flour during extrusion cooking caused serious surging problems and unstable operating conditions whereas defatted peanut flour extruded satisfactorily. Prinyawiwatkul et al. (1995) extruded the mixtures of corn starch and peanut flour, and reported that fermented and non-fermented partially defatted peanut flour can be successfully incorporated into a potential snack products. Suknark et al. (1999) produced two types snack foods, which were tapioca-fish and tapioca-peanut, by twin-screw extrusion and deep-fat frying.

Rice flour

Rice is one of the largest crops grown in the world, and yet it is one of the most under-utilized ingredients in processed foods in the Western world (Sheng, 1995). Americans, however, have doubled their consumption of rice in more than a decade, eating more than 21 pounds per person (people in Asia are said to eat as much as 300 pounds per person). According to the California Rice Commission, rice consumption in the U.S. has been increasing about 4% annually (Pszczola, 2001). In some of Asian countires, most snacks are made with rice or rice flour. Whereas, in the United States, ingredients based on corn, wheat, and oats are widely used in cereal, snacks, frozen food, dairy products, and drink mixes (Sheng, 1995).

Typically rice flour is about 75-80% starch; the remainder being moisture, protein, fat, and ash. The functional properties of rice starches are quite different from those of corn or wheat starches, primarily due to the amylose to amylopectin ratio in the rice starch component and the small rice starch granules (3-8 μm) of all grain starches. Typically, the amylose content of the common rice varieties is 22-23% for long grain, 15-19% for medium grain, and less than 1% for waxy grain (Sheng, 1995). Today, many industries use starch or its derivatives in one form or another in various applications. Depending on the type, starch and its derivatives may be used to facilitate processing, provide texture, thicken, suspend solids, yield a desired appearance, and control moisture, consistency, and shelf stability. For example, in expanded or puffed snacks, the target texture can be obtained by changing the amylose/amylopectin ratio by manipulating combinations of high-amylose and high-amylopectin starches according to the properties desired. Chinnawamy and Hanna (1988) studied the product quality of expansion ratio, bulk density, and shear strength on extrusion-cooked corn starch with different contents of amlylose from 0 to 70%. The expansion ratio increased from 8 to 16.4 as amylose content increased from 0 to 50%, and then decreased. Increasing amylose contents decreased bulk density, but increased shear strength. An effective way to increase the expansion of a snack is to add waxy grain starch, which is essentially 100% amylopectin. However, one problem with high-amylopectin starch is the breakdown of amylopectin molecules by the high-temperature/high-shear processing conditions experienced during cooker extrusion and frying (Huang, 1995). It has been reported that starch content and quality (amylose and amylopectin) most significantly affect expansion ratios as among different types of starches only a few types expand better than the others (Mercier and Feillet 1975). The relationship between materials and expansion ratio was often used to determine the product quality of expanded products produced under different extrusion conditions. Mercier and Feillet (1975) observed that starches with low (waxy) and high-amylose contents expand best at 135 and 225ºC, respectively. Expanded volume of cereals and starches decrease with increasing amounts of proteins or lipids in the feed material, but increase with increasing starch content (Faubion et al. 1981; Peri et al. 1983; Linko et al. 1981; Mercier and Feillet 1975). Suknark et al. (1997) extruded the blends of partially defatted peanut flour (PDPF) and different types of starch, and reported that regardless of PDPF content, as amylose content of starch increased, the expansion ratio increased.

The uses of rice as a food ingredient keep expanding, with it's functional and health benefits being actively promoted (Pszczola, 2001). Rice flour can improve the texture and handling of multigrain products. Blending long grain rice flour increases the crispness and expansion in fried or baked snack chips based on wheat or corn. In addition, the bland taste of rice flour allows improvements in functional properties without altering the taste of the finished products (Sheng, 1995). Rice flour blends also work well in fried chip products by reducing oil absorption. Chips made with 100% rice flour absorb 20-30% less oil during frying (Sheng, 1995). Huang (1995) reported that high-amylose starches can be used to reduce oil absorption in fried snacks, due to their strong film-forming properties. USDA agricultural research service's Southern Regional Research Center also reported that rice-based ingredients can help reduce the oil content of such foods as deep-fat fried doughnuts and battered-fried chicken. Doughnuts made from dough containing small amounts of modified rice starch, rice flour, and other ingredients reportedly absorbed as much as 70% less oil during frying than traditional, all-wheat doughnuts; compared to all-wheat doughnuts, which had 24-26 grams of oil, the wheat-rice flour doughnuts had as little as 8 grams (Pszczola, 2001).

IV. CELL STRUCTURE ANALYSIS

Cell Structure and Texture

Among the "sensory acceptability factors", appearance, flavor, and texture, texture is certainly the most important descriptor to qualify crispy products (Bourne, 1982). Crispy food products have increased their impact in the food market in the last two to three decades as they provide energy, comfort, and pleasure to consumers, and they are still expected for a large development in coming years (Bouvier et al., 1997; Guraya and

Toledo, 1994). The texture attributes of crispness and crunchiness are the most important descriptors to make crispy and low moisture snack foods. They relate to brittleness and fracturability, as the structure of crispy products tends to collapse with brittle fracture and a rapid decay of the force after fracture: this occurs with very low shear strength and work for mastication. The breakdown of structure may generate small and numerous pieces, associated with sound effects (Vickers and Bourne, 1976; Christensen and Vickers, 1981; Seymour and Hamann, 1988). The texture of food products can be determined by their structural characteristics, such as cell size, and uniformity, and mechanical properties. Gao (1999) reported that expanded food products, as they are three-dimensional structure of an intricate network of interconnected air cells and cell walls formed during the puffing process, are generally quite cellular, porous, and low in density, and that their cellular structures are the most important texture-related geometric properties.

The structural properties of expanded extrudates depend mainly on cell size, cell distribution, and cell organization. The cellular structure together with cell wall characteristics determine both the physical properties, such as the mechanical and acoustical properties, as well as the sensory profile of the extrudates (Bouvier et al., 1997). The cellular structure is visible and the material properties to some extent reflect on the cellular structure, surface roughness, color, and other visible characteristics (Gao and Tan, 1996a). Mechanical properties are another important aspect of expanded-food texture. The mechanical properties are associated with mechanical strength and deformation, and related to their cellular structure (Gao and Tan, 1996b).

Szczesniak (1963) classified textural characteristics into three main categories; mechanical characteristics, geometrical characteristics, and “other characteristics” referring mainly to moisture and fat contents of the food. Mechanical characteristics are the most important in determining how a food behaves in the mouth, and are manifested by the reaction of the substance to stress. Mechanical characteristics can be broken down into five primary parameters and three secondary parameters. The five primary parameters are hardness, cohesiveness, viscosity, elasticity, and adhesiveness. The first four parameters are related to attractive forces between particles of food, whereas adhesiveness is related to surface properties. The secondary parameters of the mechanical characteristics are brittleness, chewiness, and gumminess. Geometrical characteristics are classified into two groups; those related to particle size and shape, and those related to particle orientation. The division termed, “other characteristics”, is comprised of mouthfeel qualities related to the perception of moisture and fat content in a food.

For routine process monitoring and quality control, the texture-related geometric and mechanical properties are usually measured by instrumental methods. The most widely used instrumental method for mechanical property measurement is shear or compression test on an Instron universal testing machine resulting in a strain-stress relationship (Gao and Tan, 1996b). For geometric properties, Scanning electronic microscopy (SEM) is often used to reveal the internal structure (cross sections) and/or surface appearance in details. From SEM photographs, surface roughness can be observed; cell size, shape, and density (count per unit area) can be examined or estimated (Gao and Tan, 1996a).

There are many advantages in using scanning electronic microscopy (SEM) compared to light miceroscopy and transmission electron microscopy. The SEM has a large depth of field defined the extent of the zone on a specimen, which appears acceptably in focus at one time. SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is relatively easy since most SEM only requires the sample to be conductive. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research area today (Peleg and Bagley 1983).

Scanning Electron Microscopy (SEM)

A scanning Electron Microscopy (SEM) is the microscopy that uses electrons rather than light to form an image. The SEM generates a beam of electrons in a vacuum that is collimated by electromagnetic condenser lenses, focused by an objective lens, and scanned across the surface of the sample by electromagnetic deflection coils. Once electron beam hits the sample, other electrons (secondary or backscattered) are ejected from the sample. Detectors collect the secondary or backscattered electrons, and convert them to a signal that is sent to a viewing screen similar to the one in an ordinary television, producing an image. By scanning with an electron beam that has been generated and focused by the operation of the microscopy, an image that is a good representation of the three-dimensional sample is formed. When a SEM is used, the column and sample must always be at vacuum. If the column were full of air, the electrons would collide with the gas molecules and never reach the sample. If gas molecules react with the sample, different compounds could form and condense on the sample. This can lower the quality of the image.

Scanning Electron Microscopy (SEM) has been used to determine the cell structure distribution and the relationship between internal structure and textural properties under extrusion processing: cell size distribution can indicate that how finely or coarsely the material is subdivided. Gao and Tan (1996a, b) characterized the surface and cross-section images of a yellow corn meal extrudate product and measured the cell size and density using SEM photographs. In addition, Tan et al. (1997) examined the cellular structure of puffed corn meal extrudates using SEM images, and reported that a number of image features were found to be good indicators of the cell distribution.

V. SOUND ANALYSIS

Sound Wave

The Nature of Sound Wave: Sound is a wave, which is created by vibrating objects and propagated through a medium. A wave can be described as a disturbance that travels through a medium, transporting energy from one location to another location. Sound wave can be characterized into three aspects. Since a sound wave is transported through a medium via the mechanism of particle interaction, a sound wave is characterized as a mechanical wave. Sound waves are longitudinal wave because particles of the medium through which the sound is transported vibrate parallel to the direction through which the sound moves. Because of the longitudinal motion of the air particles, there are regions in the air where the air particles are compressed together and other regions where the air particles are spread out. These regions are known as compressions and rarefactions, respectively. Since a sound wave consists of a repeating pattern of high pressure (compressions) and low pressure (rarefactions) regions moving through a medium, it is referred to as a pressure wave (Henderson, 2001).

Theoretical Aspects of Sound: All brittle objects deform when subjected to a mechanical force. The deformation of a brittle object due to a mechanical force, leads to the displacement of atoms from their equilibrium positions to new state levels having metastable potentials. These potentials induce reaction forces which oppose the deformation and which tend to return the structure to its original state. At the macroscopic level, the emitted signals depend on the geometry, i.e., length, width, thickness, whereas at the microscopic level, they depend on the molecular and atomic disposition of the product, on chemical bonds, impurities, and eventually on pre-existent micro-cracks. The mechanical energy brought to the system during deformation can be stored in the form of an increase of the internal energy resulting from the modification of interatomic bonds. Hence, the work performed by the external forces during deformation is stored in the system in the form of elastic potential energy. The rupture obtained as the applied stress reaches a critical value, induces an instantaneous liberation of the partially transformed energy in the form of acoustical energy; the moment of rupture reflects the moment of destruction of the interatomic bonds at a given point (e.g., crack or defect) and the instantaneous liberation of other atoms who will want to regain their stable stage (initial) due to and via the elasticity of the body. This perturbation in the structure produces the sound wave (Chakra et al., 1996).

Digital Signal Processing (DSP)

Electrical quantities in the analog domain are voltage, charge, current, and power. Conversely, signals in the digital domain represent numbers, characters, or other specific information (Randall and Tech, 1987). During analog recording the voltages are stored directly as they come from the microphone. Deriving a digital waveform from an analog waveform is the objective of digitizing sound (Pelton, 1993). Two processing steps are required to digitize an analog signal: sampling, which discretizes the signal in time, and quantizing, which discretizes the signal in amplitude. During digitization, an analog waveform is sampled at a fixed rate, and quantization takes place at each sample time when the waveform's amplitude is measured (Pelton, 1993).

The parameters that determine the quality and quantity of digital sound are sampling rate, number of bits, and number of channels. The sampling rate is the number of times per second that sound data is recorded. A high sampling rate will yield a high quality digital sound in the same manner that high graphics resolution will show better picture quality (Eargle, 1980). If the digital waveform is to uniquely represent the analog waveform, then the sampling rate must be at least twice the highest frequency present in the analog signal known as "Nyquist Frequency" (Speaks, 1992; Pelton, 1993): In other words, in digital systems, the maximum frequency that can be played back is one-half of the sampling rates. Sampling at this rate will not result in any loss of information. But if sampling rate is less than this, the collected information will be distorted: this is known as the "aliasing effect". Aliasing occurs when the input sound contains frequencies above the Nyquist frequency resulted in the sampling process does not collect enough data to correctly determine the shape of the sound wave. The number of bits determines how accurately the amplitude of a sample is recorded: for example, A sampling rate at 44100Hz , 16 bits yields better quality and more accurate data than those at 22050Hz, 8 bits. The number of channels for digitization can be either mono or stereo. A single-channel sound, called mono sound, contains information for only one speaker (similar to AM radio), whereas a two-channel sound, called stereo sound, contains data for two speakers (similar to FM radio) (Eargle, 1980; Randall and Tech, 1987). Principles of digital signal processing may be used in analyzing food quality and processing conditions. Pugh (1994) used sound waves to study watermelon maturity using an electronic thumper sorting device that increases the percentage of high quality melons in retail outlets. Fu et al. (1994) quantified the degree of bumping due to the explosion of food during microwave heating using digital signal processing. Gatchalian et al. (1994) observed that the maturity of coconut could be correlated to the sound wave due to different chemical characteristics such as moisture, crude fat, starch, and soluble solids.

Frequency analysis

In acoustics, a signal is fluctuations in pressure, which exist in the path of a sound wave. A common signal is assumed to be composed of a number, perhaps an infinite number, of sinusoidal components at various frequencies, each having a given amplitude and initial phase. Fast Fourier Transform (FFT) analysis can be used in analyzing the frequency compositions of a waveform. A common use of FFT is to break down the sound into pure tones at different frequency components, and find the frequency components of a signal buried in a noisy time domain signal where it is difficult to identify the frequency components. (Randall and Tech, 1987).

The power content of each frequency is related directly to the square of the amplitude of the Fourier series component. The spectrum of squared amplitudes is known as the "power spectrum", and this is often the most useful part of the whole sound spectrum (Randall and Tech, 1987). The spectral components have the dimensions of "spectral density" when the spectrum is a continuous function of frequency. In addition, a sound spectrum represents the energy present in the sound over a period of time (Pelton, 1993).

Fast Fourier Transformation (FFT) has been used in many studies to analyze the frequency components of the digitally recorded sound signals five snack food products at two moisture levels (Liu and Tan 1999), to determine the texture characteristics of crispness, crunchiness, and crackliness by biting eight foods (Dacremont 1995), and characterize the structure properties of pasta based on sound emission (Chakra et al. 1996).

VI. SENSORY EVALUATION

Sensory evaluation is one of the most important activities in product development being necessary throughout the various stages in the product cycles (ASTM, 1979). These states include the development of the product itself, product maintenance, product improvement, and optimization, and assessment of market potential. Sensory evaluation is often used to determine whether or not an optimum product has been developed (Giovanni, 1983). In any scientific endeavor, optimization may be considered a procedure for developing the best possible product in its class. This definition implies that a measurement of "best possible" is provided: in sensory evaluation, this means responses for the most liked or most preferred products. In its most general sense, the phase "product optimization" stands for the disciplined approach to product development, whereby the investigator systematically varies formula and processing conditions. Optimization in sensory evaluation is to identify variables or combinations of variables that are important to sensory acceptance and then to determine a degree of importance for each (Sidel and Stone, 1983). The typical sensory optimization identifies specific sensory attributes, ingredients, or processing variables that will result in optimal product acceptance. An optimal processing formulation maximizes consumer acceptance in that it is the best possible formulation given a fixed set of ingredients (Sidel et al., 1994).

Consumer sensory research can be classified into two major categories, Qualitative and Quantitative analysis. Quantitative research involves measurements, whereas qualitative consumer research methods are descriptive, and both are used in defining critical attributes of a product. Consumer preference and quantitative descriptive data can provide valuable information during new product development and improvement. Consumer preference data can provide information on a product's acceptance or consumer perception of its integrated attributes, but consumers are not able to use words and numbers accurately to describe specific product characteristics that only a trained panel can provide (Meilgaard et al., 1991). Conversely, a trained panel provides a precise, reliable qualitative and quantitative description on the attribute of a product, but not its acceptance (Munoz and Chambers 1993).

Quantitative Descriptive Analysis (QDA)

The Quantitative Descriptive Analysis (QDA) method is well suited for optimization research. After a screening of panelists' sensory skills, the subjects who provide the attribute responses develop attributes that are non-technical in their content and provide quantitative measures of product similarities and differences.

Principles: The method of quantitative descriptive analysis (QDA) is based on the principle of a panelist's ability to verbalize perceptions of a product in a reliable manner. QDA technique embodies a formal screening and training procedure, development and the use of a sensory language, and the scoring of products on repeated trials to obtain a complete, quantitative description (Stone, 1992). Quantitative Descriptive Analysis methods involve the detection and the description of both the qualitative and quantitative sensory aspects of a product by trained panels. Panelists must be able to detect and describe the perceived sensory attributes of a sample. In addition, panelists must learn to differentiate and rate the quantitative or intensity of a sample and to define to what degree each qualitative note is present in that sample (Meilgaard, 1991). These descriptive sensory methods are used in research and development, and manufacturing to define the sensory properties of a product, document product attributes before a consumer test, track a product sensory changes over time, and map perceived product attributes for the purpose of relating them to instrumental, chemical, and physical properties (Szczesniak, 1975; Moskowitz, 1979).

Components of QDA: The perceived sensory parameters, which define the product, are referred to by various terms, such as attributes, characteristics, descriptors, or terminology: this is called qualitative aspect of descriptive analysis. These qualitative factors include terms, which define the sensory profile of the sample (Johnsen et al., 1988; Jeltema and Southwick, 1986). The selection of sensory attributes and the corresponding definition of these attributes should be related to the chemical and physical properties of a product, which can be perceived (Civille and Lawless, 1986). The quantitative aspect, intensity, of a descriptive analysis expresses the degree to which each of the characteristics (terms, qualitative components) is present. This is expressed by the assignment of some value along a measurement scale.

Scaling: Scaling techniques involve the use of numbers or words to express the intensity of perceived attributes, such as sweetness, hardness, and smoothness. Line scales are in common use in descriptive analysis. The panelist rates the intensity of a given stimulus by making a mark on a horizontal line, which corresponds to the amount of the perceived stimulus. The lengths most used are 150mm or 6 in. with marks ("anchors") either at the ends or ½ in. or 12.5mm from the two ends. Normally the left end of the scale corresponds to "none" or zero amount of the stimulus while the right end of the scale represents a large amount or a very strong level of the stimulus (Stone and Sidel, 1985).

Consumer Affective Tests

The primary purpose of consumer affective tests is to assess the personal response (preference and/or acceptance) by current or potential customers of a product, a product idea, or specific product characteristics. The reasons for conducting consumer tests usually fall into one of the following categories: product maintenance for quality control, quality assurance and shelf life, and storage projects, product improvement / optimization for improving the desired attributes and hence the overall consumer acceptance, development of new product, and assessment of market potential (Meilgaard et al., 1991). Consumer affective sensory evaluation is usually performed towards the end of the product development or reformulation cycle. In consumer sensory analysis the investigator is interested in whether the consumer likes the product, prefers it over another product, or finds the product acceptable based on its sensory characteristics (Stone and Sidel, 1993).

Consumer affective test consists of qualitative and quantitative methods. Qualitative tests (e.g., focus group) are those, which measure subjective responses of a sample of consumers to the sensory properties of products by having those consumers talk about their feelings in an interview or small group setting. Conversely, quantitative affective tests are those (e.g., consumer acceptance test), which measure ratings with responses of a large group (50 to 400) of consumers to a set of questions regarding preference, liking, sensory attributes, etc (Meilgaard et al., 1991).

Focus Group: A focus group interview is a carefully planned session designed to obtain several individuals' perceptions of a defined area of interest in a permissive, non-threatening environment. It is conducted with approximately six to nine people by a skilled moderator (Casey and Krueger, 1994). Focus groups are used to obtain information about their reaction to products and concepts, and to investigate various other aspects of respondents' perceptions and reactions: consumers' attitudes, opinions, perceptions, behaviors, habits, and practices (Resurreccion, 1998; Chambers and Smith, 1991). The primary interest in conducting a focus group is in generating the widest possible range of ideas and reactions, so the focus group method is often used in the very early assessment of a prototype (ASTM, 1979). A focus group offers several advantages. It encourages and captures interaction among participants, and this technique provides information that is difficult to obtain with other methods. As focus group discussions have high face validity, clients can easily understand the technique and typically find the results credible. There are also limitations to focus group. Moderators must be trained to conduct the interviews. The moderator must become skillful in encouraging the participation of everyone and preventing a few individuals from dominating the group's interactions. Moderators must be masterful at eliciting information from others while holding in check their personal points of view. Groups are difficult to assemble. Identification and recruitment of participants is time-consuming and requires systematic processes with sufficient incentives. As a research method, focus groups offer a unique research methodology that can complement other types of food preference research. The technique enables researchers to get close to the customer and obtain information about preferences and behaviors (Casey and Krueger, 1994).

Consumer Acceptance Tests: Acceptance tests are used to determine overall liking for a product, to determine liking for broad aspects of product sensory properties (aroma, flavor, appearance, texture), and to measure consumer responses to specific sensory attributes of a product, which are used as predictor variables for consumer acceptance. An acceptance test is used when a product researcher needs to determine the "affective status" of a product, e.g., how well it is liked by consumers (Meilgaard et al., 1991).

Acceptance measurements can be done on single products and do not require a comparison to another product. The most common measurement scale is the 9-point hedonic scale (Peryam and Pilgrim, 1957), also known as a degree-of-liking scale. The hedonic scale assumes that consumer preferences exist on a continuum and that preference can be categorized by responses based on likes and dislikes. Samples are served to panelists monadically (one at a time), and the panelists were asked to indicate their hedonic response to the sample on the scale. From relative acceptance scores one can infer preference; the sample with the higher scores is preferred. The words chosen for each scale option is based on equal interval spacing, thus the scale, psychologically, has ruler-like properties. This equal-interval property is important in the assignment of numerical values to the response choices and to the use of parametric statistics in analysis of the data. The 9-point scale is very simple to use and is easy to implement. It has been widely studied and has been shown to be useful in the hedonic assessment of foods, beverages, and nonfood products (Stone and Sidel, 1993).

Sensory Data Analysis

The optimization of all aspects of a product is the goal in product development. Optimization studies should include sensory information from both descriptive and consumer tests. The critical quality attributes important to consumers can be determined through the focus group technique. These characteristics can then be quantified through descriptive analysis; furthermore, consumer tests can determine the predicted acceptability. Theoretically, a specific set of sensory properties as well as a set of physical and chemical attributes, if present, would lead to optimum acceptance (Schutz, 1983).

Response Surface Methodology (RSM) is a popular method for product optimization within the sensory evaluation field (Henika, 1982). RSM can be defined as a statistical method that uses quantitative data from appropriate experimental designs to determine and simultaneously solve multivariate equations, which specify the optimum product for a specified set of factors through mathematical models. These equations can be graphically represented as response surfaces which can be used in three ways: (1) to describe how the test variables affect the response; (2) to determine the interrelationships among the test variables; and (3) to describe the combined effect of all test variables on the response (Giovanni, 1983).

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SECTION II

PROCESSING HALF-PRODUCTS USING A TWIN-SCREW EXTRUDER AND FINAL SNACK PRODUCTS

PROCESSING HALF-PRODUCTS

Materials

Partially defatted (12% fat), lightly roasted peanut flour were purchased from Golden Peanut Company (Golden Peanut, Alpharetta, GA), and rice flour, a long grain variety, was purchased at RivLand partnership (RivLand, Houston, TX). Salt (Morton international, Inc., Chicago, IL) was purchased at local market (Kroger, Griffin, GA).

Sample Preparation

Three batches of peanut and rice flour mixture were prepared by blending at three levels of peanut flour: 30, 40, and 50% (dry basis). Approximately 20kg batches of each mixture, that also contained 2% salt, were mixed in a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY) for 20 minutes. After blending, the mixture was packed in 49 liter. plastic bags (Pactiv Corporation, Lake Forest, IL) and stored at 3-5ºC overnight for use of next day. The moisture content of each blend was adjusted to 40% (wet basis) directly in the extruder during the extrusion processing by use of a calibrated, proportioning pump (Type N-P 31, Bran & Lubbe, Buffalo Grove, IL). This approach was used because the peanut and rice flour blend became sticky and difficult to feed if adjusted to 40% moisture prior to extrusion.

Experimental Design

A 3 × 3 × 3 full factorial design was used. Experimental variables were three levels of peanut flour (30, 40, and 50%), three levels of screw speed (200, 300, and 400rpm), and three levels of feed rate (4, 5, and 6kg/hr). The temperature profiles were set at 100º, 120º, and 110ºC for first (near the feed hopper), second, and third barrel zone, and the last two zones near the die and at the die were set at 95º and 80ºC, respectively. The mixture of peanut and rice flour was fully cooked in the extruder barrel, cooled in the terminal barrel, force through the die, and shaped at temperature below 100ºC. This low temperature prevents the puffing caused by water turning to steam as normally observed in directly expanded products. Moisture content of the mixtures was adjusted to 40% (wet basis).

Extrusion Processing

The mixtures of peanut and rice flour were extruded in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England) with length to diameter ratio of 25:1 and equipped with a slit die of dimensions 1mm × 20mm. The length and diameter of the extruder barrel were 750 and 30mm, respectively. Feed materials were delivered through a volumetric screw feeder (Model K2VT20, K-Tron Corp., Pitman, NJ), which was calibrated previously to determine the settings that would deliver each batch at a feed rate of 4, 5, and 6kg/hr (dry basis). The feed materials were dropped into the unheated feed zone through an inlet port and were carried by the screw through the four heated zone of the extruder barrel and finally out through the die. The extruder had a clam-shell barrel consisting of four independent temperature zones (barrel zone 1, 2, 3, and 4) controlled by electrical heating and water cooling; and one heated zone at the die. The temperature profile of the heating zones was set to be 100º, 120º, 110º, 95º, and 80ºC from feed zone to die. The screw profile featured eleven sections configured with a combination of twin lead forwarding screw elements and paddles to facilitate conveying, working, thorough mixing and cooking of the feed materials (Table 2-1). The first section contained two sets of forwarding screw elements that conveyed

Table 2.1 Screw configuration used for the extrusion process of half-products

Section (#)	Screw Elements	Number of elements (#)	Section length (D)
1	twin lead screw	3	1.5
	twin lead screw	1	1.0
2	30º forward paddle	5	0.25
3	twin lead screw	1	1.5
	twin lead screw	1	1.5
4	90º paddle	6	0.25
	30º forward paddle	1	0.25
5	twin lead screw	1	1.5
	twin lead screw	1	1.0
6	90º paddle	5	0.25
	60º forward paddle	1	0.25
7	twin lead screw	1	1.5
	twin lead screw	1	1.0
8	90º paddle	5	0.25
	60º forward paddle	1	0.25
9	twin lead screw	2	1.5
10	60º forward paddle	8	0.25
11	single lead discharge screw	1	1.0

D=25mm

the raw materials through the unheated zone as the moisture was introduced into the barrel. The first of the mixing sections made up of forwarding paddles was positioned as the materials entered the first heated zone. The fourth, sixth, and eighth sections of the screw profile were configured with 90º and 30º/60º forward paddles to facilitate kneading and thorough working of the dough mass. The final set of forward paddles was the tenth section. Twin lead feed screws (sections 3, 5, 7, and 9) interspersed these sections configured with working components (paddles) to transport the dough through the barrel. The screw speed was set at 200, 300, and 400 rpm, and the pressure build up in the barrel during processing was monitored continually by the torque reading. The water pump was calibrated to determine the set point to give 40% moisture content for experimental runs of the peanut and rice flour mixture.

PROCESSING PUFFED SNACK PRODUCTS

Drying

Upon exiting the die, extrudates were cut into 15cm-lengths and dried in a Lincoln Impinger® oven (Model 1450, Lincoln Foodservice Products, Inc., Fort Wayne, IN) at 70ºC for 5min to remove surface moisture and prevent sticking of extrudates. The extrudates were sealed in Ziploc® bags to avoid contamination. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried in a Environmental Chambers (EGC-TC2, Chagrin Falls, Ohio) at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. The half-products were sealed in Ziploc bags®, and stored in a cold room at 5ºC prior to frying.

Deep-Fat Frying

The half-products stored at 5ºC in cold room were equilibrated at room temperature overnight before frying. Half-products weighing 30g each (30-35 pieces) were deep-fat fried at 200 ± 5ºC for 35-40sec in natural vegetable oil using a Wells Fryer (Model F-48, Wells Mfg, Co., San Francisco, CA). Products puffed by frying were drained on paper towels and cooled at ambient temperature. Samples were freshly prepared for each evaluation.

SECTION III

CONSUMER-BASED OPTIMIZATION OF AN EXTRUDED SNACK PRODUCT USING RESPONSE SURFACE METHODOLOGY (RSM)

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ABSTRACT

Blends of partially, defatted peanut flour (12% fat) and rice flour at different ratios were extruded using a twin-screw extruder. The extrudates were dried (11-12% moisture), and expanded by deep-fat frying. The effects of peanut flour, feed rate, and screw speed were studied. A consumer acceptance test was conducted to measure overall liking. Peanut flour was the most important factor that affected to the consumer acceptability. Response Surface Methodology (RSM) was used for optimization. The optimum area was bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR. Verification revealed the predictive ability of the models for consumer acceptability.

INTRODUCTION

Consumer acceptance plays a very important role in the success of a particular product in the market. A high level of acceptance to the target consumers is an essential prerequisite for a successful product (Land, 1988). Moreover, consumer perceptions and acceptance of a product are becoming critical elements in defining quality. Munoz et al. (1992) emphasized that it is the "person whose needs are being satisfied" who determines quality – the consumer. In addition to this, sensory quality, specifically, was defined by Fishken (1990) as the acceptance of the sensory characteristics of a product by consumers who are the regular users of the product category.

Consumer affective testing has been used to determine preference, liking, or attitudes about a product concept, product, or specific product characteristics (Chambers and Wolf, 1996). In most food research situations, information from consumers is the basis for important decisions such as the development and marketing of new products, the reformulation of existing products, and the establishment of quality control/sensory specifications. Either hedonic/acceptance or diagnostic (e.g., attribute intensity) data can be collected from consumers. Hedonic data provide the most important and reliable information, because consumers are the only people who can accurately and reliably indicate the degree of liking or preference for a product (Munoz, and Chambers, 1993). Walker and Resurreccion (2000) studied sensory profile and consumer acceptance for cracker-coated peanuts, and reported that a maximum consumer overall acceptance ratings of 6.0 ("like slightly") was obtained for the products. Suknark et al. (1998) reported Asian and American consumers rated overall acceptance of an extruded peanut snack formulated with tapioca-based starch "like moderately (7.0)". Consumers rated peanut-sweet potato cookies “like slightly” or better (>6.0) for overall acceptance (Palomar and others, 1993). The use of quantitative test, such as analytical measurements and descriptive sensory analysis, as means of predicting complex human response, like consumer acceptance, is common, especially because direct information about human subjects and their response is usually costly to obtain (Harper, 1988). There may be other factors that need to be considered if consumer acceptance of a product is to be predicted. These include production limitations and cost among samples, and situational or environmental variables (Meiselman et al., 1988).

Consumer affective tests have been chosen by researchers and manufacturers as a useful method to optimize the sensory attributes in a product. Product optimization is a procedure for determining the best possible or most favorable formulation and process for a product or procedure in its class. This definition implies that an opinion, or measurement, of “best possible” is provided; in consumer acceptance tests, this means responses for the most liked or most preferred product. Sensory product optimization integrates descriptive analysis, analytical, and consumer acceptance information to develop mathematical models describing the relationship between ingredients and processing variables (Sidel and Stone, 1983). An optimal formulation maximizes consumer acceptance in that it is the best possible formula or ingredient combination as determined by the target consumer of the product (Fisken, 1983). These models provide detailed quantitative guidance for product improvement and developing new products (Sidel and Stone, 1994). Optimization would mean the determination of the values for process and formulation variables that would result in product with sensory characteristics, which make them acceptable to consumers.

The objective of this study was to characterize the sensory profiles and determine the acceptance of peanut-based extruded snacks. Specific objectives were to 1) determine sensory profiles varying to peanut flour and the extrusion processing conditions of screw speed and feed rate using descriptive analysis, 2) develop predictive models for the responses of sensory attributes of consumer test, 3) determine optimum formulation and extrusion processing conditions for producing peanut-based extruded snack products, and 4) verify consumer acceptance for an optimum formulations and operating conditions.

MATERIALS & METHODS

Materials

A mixture of peanut and rice flour was blended at three levels of peanut flour (30, 40, and 50%) to rice flour using a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY), and was extruded at three levels of feed rate (4, 5, and 6kg/hr) and screw speed (200, 300, and 400rpm) in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England). The temperature profiles of the extruder barrels was set to be 100, 120, 110, 95, and 80ºC from feed zone to die. The barrel temperatures of zone four and five was set blow 100ºC to prevent puffing of extrudates. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. Half-products were puffed by deep-fat frying at 200 ± 5ºC for 35-40sec in pure vegetable oil (The detailed procedure to produce half-products and final snack products is in Section II).

Sample Preparation

The half-products with 11-12% moisture content were sealed in Ziploc® bags, and stored in a cold room at 5˚C. The puffed snack samples were prepared the day before the test day by deep-fat frying in vegetable oil. Six or seven pieces of snack samples were placed and sealed in snack size Ziploc® bag (Johnson & Son, Inc., Racine, WI) coded with three-digit random numbers.

Consumer Acceptance Tests

Consumer acceptance tests were conducted to evaluate the overall acceptance of peanut-based extruded snacks. A central composite experimental design (CCD) (Montgomery, 1997) was applied to produce snack product formulations for Response Surface Methodology (RSM) (Montgomery, 1997). 15 snack formulations were selected out of 27 formulations produced by 3×3×3 full factorial design by extrusion processing. Each snack product was evaluated by 40 consumers, and each consumer evaluated 10 samples. These were presented in random order determined using a Randomized Incomplete Block Design (Cochran and Cox, 1957), because an individual consumer finds it increasingly difficult to evaluate the product, as the number of samples presented becomes larger. Sixty consumers were recruited from near Griffin, GA. and surrounding communities to participate in the test. Criteria for recruitment of the participants were that they eat snack food once a week, were from 18 to 70 year of age, had no any food allergies (especially peanut), and were available and willing to participate on the test day. The test was conducted in an environmentally controlled sensory laboratory with partitioned booths illuminated with two 50W white incandescent bulbs providing 738 lux of light, and free from environmental elements that would distort normal perceptions.

Consumers were asked to evaluate acceptability of overall liking, color, appearance, flavor, crispness, and texture of products. Paper ballots were provided for each sample using 9-point hedonic scale (Peryam and Pilgrim, 1957) wherein 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor like, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

Test Procedure: Two sets of five samples each (10 snack products) were presented sequentially and monadically to each consumer. Consumers were asked to place 2-3 pieces of the samples in their mouths and answer the questions on the paper ballot provided for each sample: 10 paper ballots were provided for two sets of snack samples. Consumers were instructed by the server to properly fill out their paper ballots. Participants were instructed to take a compulsory 5-min break between each set of samples. They were likewise told to rinse their mouth with water between samples. Through the paper ballot each consumer was asked to decide how much they liked or disliked each sample and to mark the scales accordingly (Chambers and Wolf, 1996). Consumers were required to complete and sign a consent form approved by the University of Georgia Institutional Review Board prior to participating in the testing sessions. In addition consumers filled out a demographic questionnaire that covered the consumer's background information before the sensory evaluation test. An honorarium of ten dollars was provided.

Statistical Analysis and Modeling

Consumer acceptance data were analyzed using Statistical Analysis System (SAS Institute, Inc., 1988) (Galvez, 1992). A multiple quadratic regression models were fitted to the data using regression analysis (PROC REG) to determine the behavior of the response variables (overall liking, color, appearance, flavor, crispness, and texture) in relation to the set of independent factors (peanut flour, screw speed, and feed rate): significant variables were determined at 10% level of significance. Those significant variables determined from the regression procedure (full model) were subjected to stepwise regression analysis (PROC STEPWISE) to determine the final reduced models. Linear terms were retained in the model when a quadratic or a cross-product term involving that linear term met the above criterion.

Multiple regression analysis (PROC REG) was used to finalize the models (reduced model) after significant factors for each variable were determined from the stepwise procedure. The F-statistic was calculated, and the full and reduced models were compared with the appropriate tabular value at α=0.10 (Swindell, 1970).

$$F = \frac{(SSE^{*} - SSE) / (df^{*} - df)}{SSE / df}$$

where, SSE^{*} = sum of squares for error for reduced model

SSE = sum of squares for error for full model

df^{*} = degrees of freedom for reduced model

df = degrees of freedom for full model

If F –value exceeds the tabular value then the reduced model is significantly different from the full model at $\alpha = 0.10$ and, probably should not used. Otherwise, the reduced model is not significantly different from the full model at $\alpha = 0.10$ and, therefore, was used to predict a particular response variable. Therefore, the final reduced model was one that was not significantly different from the full model at the α=0.10 as determined by the F-statistic.

Optimization

Response Surface Methodology (RSM) was used to determine the effects of the response variables, which were overall liking, color, appearance, flavor, crispness, and texture on the consumer acceptance of peanut-based extruded snacks. Prediction models obtained were used to plot contour maps representing the combinations of the independent factors that were found to have significant effects on the attributes in consumer acceptance test of the products. Plotting was done using two factors at a time with the remaining factor fixed at one level. For the consumer acceptance test in this study, optimization would mean the determination of the values for formulations and extrusion process conditions that would result in products with sensory characteristics, which make them acceptable to consumers. Consumer acceptability scores of 6.0 (=like slightly) or greater for the each attribute tested were used as boundaries for optimization. The regions of acceptance scores of 6.0 or greater in each contour plot were shaded. The optimization was performed by superimposing the shaded individual contour plots resulted in the identification of the optimum area of formulation and extrusion processing conditions.

Verification of the Optimized Region

Verification of the predictive models of consumer acceptance test was conducted in an independent experiment. Three snack samples were selected from the operating ranges for producing peanut-based extruded snack products: two treatments represented the optimum region whereas the other was chosen from the outside the optimum region. The snack samples were prepared and evaluated for consumer acceptance. Fifty consumers recruited for verification: each consumer evaluated three samples according to the evaluation procedures previously described in consumer test procedure (Chambers and Wolf, 1996). Paired t-tests (Ott, 1992) procedures were used to determine if the observed values were different from the predicted values. The t-statistics were calculated as follows:

$$t = \frac{Y - E(Y)}{s / n^{1/2}}$$

where, Y = observed value
E(Y) = predicted value
s = sample standard deviation
n = number of observation

This is distributed as “student’s t” with (n-1) degrees of freedom. The test was performed by computing “t” and comparing it with the appropriate tabular value at $\alpha = 0.05$. The observed value is significantly different from the predicted value if $| t |$ exceeds the tabular value.

Ranges for Significant Sensory Profiles based on the Optimum Operating Conditions Determined Consumer-Acceptance Test

Quantitative Descriptive Analysis (QDA) was conducted to characterize the sensory attributes of peanut-based extruded snack products in the previous study. Ten trained descriptive panelists developed 22 attributes in appearance, aromatics, taste, and texture. Panelists evaluated the intensity ratings for each attribute. The 22 attributes were brown color, roughness, porosity, dryness, and puffiness for appearance, roasted peanutty flavor, multi-grainy flavor, oil flavor, and burnt for aromatic, sweet, salty, and bitter in taste, oiliness, roughness, hardness, crispness, crunchiness, fracturability, persistence of crunchiness, persistence of fracturability, oily mouthfeel, and tooth pack in texture.

Among 22 attributes, 13 significant descriptive sensory attributes were identified from statistical analysis. The predictive models for these 13 attributes were obtained, and used to predict the acceptable ranges of 13 descriptive sensory attributes. The optimum range values determined from the consumer acceptance test were applied to the predictive models of two snack products selected from the optimum regions, which were the snack products used for verification.

RESULTS & DISCUSSION

In the early years, Pilgrim (1957) initiated acceptance measurement as a means of predicting consumption. Stone and Sidel (1993) stated that acceptance testing is to measure liking or preference for a product.

Consumer Acceptance Test

Demographic Characteristics of Participants: Sixty consumers in acceptance test and fifty consumers in verification participated in the study. Demographic characteristics of 60 consumers participated in consumer acceptance test are shown in Table 3.1. The group was composed of 42% male and 58% female and primarily of Caucasians (75%) and, and married panelists made up 68% of the consumers. Seventy-five percent of the participants had some college or higher degree of education level, and the half are employed full- or part- time. The average income was $42,000.

Consumer Testing: The mean consumer acceptance ratings for overall liking, color, appearance, flavor, crispness, and texture for all snack products are presented in Table 3.2. In this study, snack products that were rated 6.0 (=like slightly) or greater on a 9-point hedonic scale were considered to be acceptable. Among all snack products, the

Table 3.1. Selected demographic characteristics of participants in consumer acceptance test (n=60)

Variables		Percentage Responding[1]
Gender	female	58
	male	42
Age, year	18 to 24	10
	25 to 34	19
	35 to 44	15
	45 to 54	24
	55 to 64	15
	65 to 70	17
Race	Caucasian	75
	Black	17
	Asian	7
	Hispanic/Spanish	2
Marital Status	Single	20
	Married	68
	Others	12
Education	9-12 years of school	12
	Graduated high school	15
	Some college	37
	Completed college	17
	Graduate or professional school	19
Employment	employed full-time	36
	employed part-time	10
	homemaker	20
	student	10
	unemployed	5
	retired	19
Household income	Under $20,000	27
	$20,000 to 29,999	17
	$30,000 to 39,999	12
	$40,000 to 49,999	14
	$50,000 to 59,999	15
	$60,000 to 69,999	5
	$70,000 and over	10

[1] Out of 100% for each demographic characteristics

Table 3.2. Mean consumer ratings for acceptability of overall liking, color, appearance, flavor, crispness, and texture of peanut-based snack products

formulation			acceptability mean ratings[a]					
PF	SS	FR	overall liking	color	appearance	flavor	crispness	texture
30	200	4	6.70(1.36)ab	7.10(1.32)ab	7.13(1.26)ab	6.35(1.56)a	7.33(1.05)abc	7.08(1.14)a
30	200	6	6.43(1.22)abc	6.93(1.02)abc	6.85(1.23)abc	6.15(1.63)ab	7.30(1.18)abc	6.68(1.51)abc
30	300	5	6.53(1.34)abc	7.00(1.15)abc	6.98(1.14)abc	6.48(1.48)a	7.35(1.12)abc	7.05(1.26)a
30	400	4	6.85(1.59)a	7.40(1.19)a	7.28(1.22)a	6.45(1.74)a	7.38(1.53)ab	7.13(1.54)a
30	400	6	6.33(1.42)abc	6.70(1.2)abc	6.85(1.12)abc	6.05(1.74)ab	7.25(1.1)abcd	6.50(1.55)abcd
40	200	5	6.33(1.53)abc	6.30(1.26)cde	6.43(1.32)bcde	6.20(1.520a	6.98(1.44)abcde	6.75(1.37)abc
40	300	4	6.05(1.68)abcd	6.53(1.54)bcd	6.53(1.47)bcd	5.88(1.84)abc	6.90(1.39)abcde	6.58(1.53)abcd
40	300	5	6.63(1.35)ab	6.45(1.32)bcd	6.50(1.26)bcde	6.43(1.74)a	7.43(1.13)a	6.88(1.4)ab
40	300	6	5.95(1.65)bcd	6.33(1.47)cd	6.35(1.48)cde	5.85(1.67)abc	6.98(1.46)abcde	6.38(1.5)abcd
40	400	5	6.40(1.15)abc	6.43(1.38)bcd	6.40(1.39)bcde	6.15(1.35)ab	7.20(1.18)abcd	6.85(1.29)ab
50	200	4	5.70(1.94)cd	5.80(1.88)def	5.98(1.89)de	5.73(2.1)abc	6.68(1.93)bcde	6.23(1.75)bcd
50	200	6	5.43(1.53)d	5.58(1.71)ef	5.90(1.35)de	5.15(1.78)c	6.55(1.55)de	5.85(1.61)d
50	300	5	5.78(2.01)cd	5.80(1.81)def	5.78(1.79)e	5.55(2.18)abc	6.63(1.58)cde	6.10(1.85)bcd
50	400	4	5.98(1.67)bcd	5.85(1.69)def	5.93(1.65)de	5.88(1.62)abc	6.95(1.26)abcde	6.25(1.61)bcd
50	400	6	5.50(1.99)d	5.43(1.97)f	5.83(1.69)de	5.28(2.01)bc	6.30(1.83)e	6.03(1.67)cd

[a] numbers in parentheses refer to standard deviation of 40 consumer responses. A 9-point hedonic scale was used (1=dislike extremely, 5=neither like nor dislike, and 9=like extremely)

mean values in the same column not followed by the same letter are significantly different at $p \leq 0.05$

PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

product produced with the 30% peanut flour (PF) mixture at screw speed (SS) of 400 rpm and feed rate (FR) of 4 kg/hr received the highest ratings for overall liking (6.85), color (7.40), appearance (7.28), and flavor (6.45), and also was rated very high for crispness (7.38) and texture (7.13). The snack products extruded with 30 and 40% PF were rated higher than 6.0 for all attributes except two products, which were the product extruded with 40% PF at 300rpm SS and 6kg/hr FR on overall liking and flavor, and the snack product extruded with 40% PF at 300rpm SS and 4kg/hr FR on the attribute of flavor. Whereas the snack products produced with 50% peanut flour mixture received acceptance ratings lower than 6.0 for overall liking, color, appearance, and flavor, which were considered to be not acceptable to consumers. However, consumers rated all snack products including 50% peanut flour products higher than 6.0 for the crispness and texture. Although all snack products received higher than 6.0 for the crispness and texture, the snack products produced with 50% peanut flour had low scores for other attributes in the consumer acceptance test. Generally, it appeared that snack products produced with peanut flour of 30-40% were highly acceptable to consumers on the overall liking, color, appearance, flavor, crispness, and texture.

Modeling the Consumer Acceptance of Peanut-Based Extruded Snack Products

Table 3.3 shows the analysis of variables for the attributes of overall liking, color, flavor, crispness, and texture in consumer acceptance test at 10% level of significance. The attribute of appearance was not significant at $p \leq 0.10$, so the appearance was removed from the regression models. The significant independent factors were selected at 10% level of significance from the whole models and applied to stepwise regression procedure. The significant factors obtained from stepwise procedure resulted in the final

Table 3.3. Analysis of variance for the attributes of consumer acceptance test

	attributes					
factors	overall liking	color	appearance	flavor	crispness	texture
intercept	0.297	6.379	9.841	0.058	5.498	2.16
PF	ns	ns	-1.041*	ns	0.064**	ns
SS	ns	0.014**	ns	ns	ns	ns
FR	1.978**	ns	ns	2.958***	0.192*	1.943***
PF × PF	ns	ns	ns	ns	-0.012*	-0.001*
SS × SS	ns	ns	ns	ns	ns	ns
FR × FR	-0.214***	ns	ns	-0.285***	ns	-0.213***
PF × SS	ns	ns	ns	ns	0.001*	ns
PF × FR	ns	ns	ns	ns	ns	ns
SS × FR	ns	-0.003*	ns	ns	ns	ns
PF × SS × FR	ns	ns	ns	ns	-0.00002*	ns
R^2	0.765***	0.946***	0.82	0.638***	0.729***	0.871***

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$
PF = peanut flour (%)
SS = screw speed (rpm)
FR = feed rate (kg/h)

reduced models. Table 3.4 shows the final predictive models for overall liking, color, flavor, crispness, and texture on consumer acceptance tests. Each model included all linear and quadratic terms of the individual independent factor and all cross-products of linear terms. Linear terms were retained in the model when a quadratic or a cross-product terms involving that linear term was included. The coefficient of determination (R^2) of overall liking, color, flavor, crispness, and texture were 0.76, 0.95, 0.64, 0.73, and 0.87, respectively. These models were used to plot the contour maps (Fig 1) for optimization of the formulation and extrusion processing conditions.

Optimization of Consumer Acceptance Test

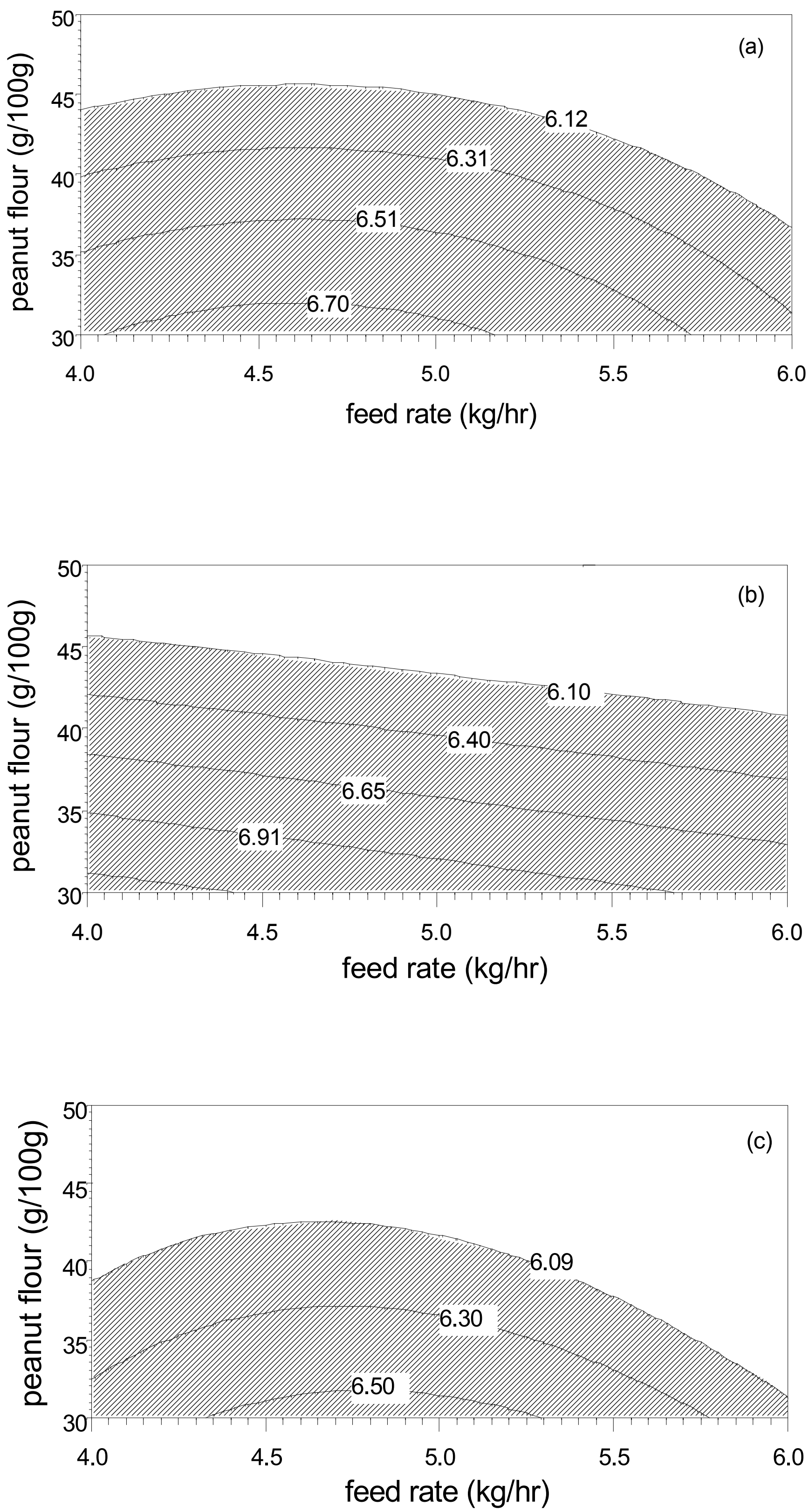
In this study, products that were rated 6.0 (=like slightly) or greater on a 9-point hedonic scale were considered to be acceptable and this was used as the boundary value for optimization of the product.

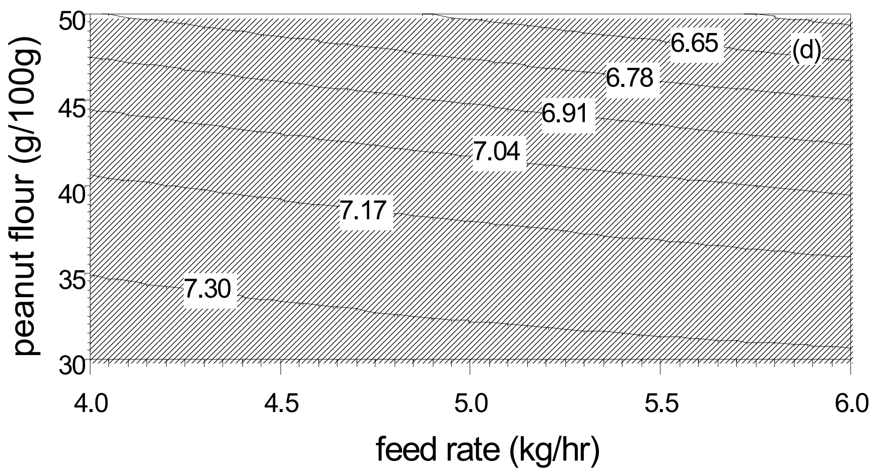
The contour plots in Fig 3.1 were obtained using the predictive models of consumer acceptance ratings for overall liking, color, flavor, crispness, and texture. Contours were plotted as a function of peanut flour and feed rate at the medium level of screw speed (300 rpm): the contour plots are based on the predictive models with screw speed kept constant and varying to the peanut flour and feed rate within the experimental range. The shaded regions represent values for consumer acceptance for each attribute of the snack products corresponding to ratings of 6.0 or greater. Fig 3.2 shows the optimum regions determined by superimposing each contour plot of overall liking, color, flavor, crispness, and texture. The shaded areas represent the optimum ranges for consumer acceptance of the attributes of the snack products tested, which satisfy acceptance ratings of 6.0 or greater. The optimum ranges were bounded by a smooth curve encompassing an area

Table 3.4. Predictive models for the significant acceptable characteristics of peanut-based snacks from consumer acceptance test

Sensory attributes	Predictive models	F-ratio	R^2
Overall liking	$E(Y) = 2.257+0.007X_1+1.978X_3-0.00064X_1^2-0.214X_3^2$	20.32	0.76
Color	$E(Y) = 6.379-0.013X_1+0.014X_2+0.474X_3-0.00023X_1X_2-0.009X_1X_3$ $-0.003X_2X_3+0.000041X_1X_2X_3$	55.12	0.95
Flavor	$E(Y) = 0.058-0.003X_1+2.958X_3-0.285X_3^2-0.007X_1X_3$	11.03	0.64
Crispness	$E(Y) = 5.498+0.064X_1+0.00013X_2+0.192X_3-0.001X_1^2+0.00012X_1X_2$ $-0.000023X_1X_2X_3$	10.36	0.73
Texture	$E(Y) = 2.16+0.05X_1+1.943X_3-0.001X_1^2-0.213X_3^2$	42.01	0.87

X_1 = peanut flour (%)
X_2 = screw speed (rpm)
X_3 = feed rate (kg/hr)


(a)
6.12
6.31
6.51
6.70
peanut flour (g/100g)
50
45
40
35
30
4.0
4.5
5.0
5.5
6.0
feed rate (kg/hr)
(b)
6.10
6.40
6.65
6.91
peanut flour (g/100g)
feed rate (kg/hr)
(c)
6.09
6.30
6.50
peanut flour (g/100g)
feed rate (kg/hr)



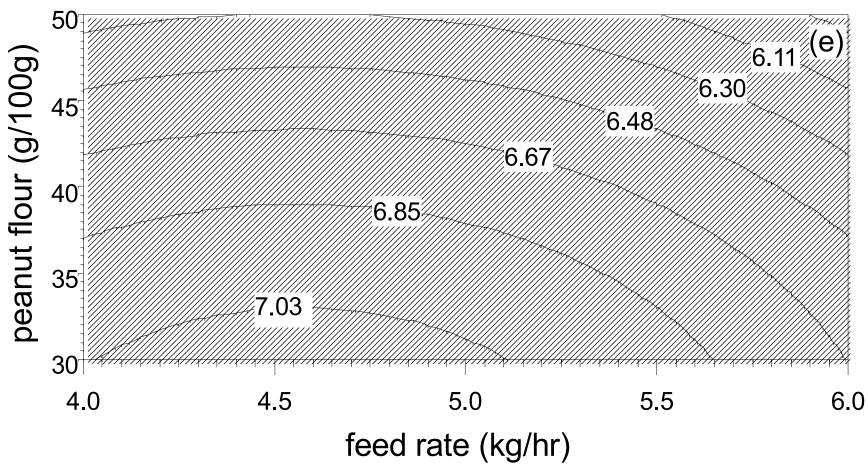


Fig 3.1. Contour plots of predictive models for consumer acceptance as a function of peanut flour(%) and feed rate(kg/hr): (a) overall liking, (b) color, (c) flavor, (d) crispness, and (e) texture. The screw speed was kept constant at 300rpm.

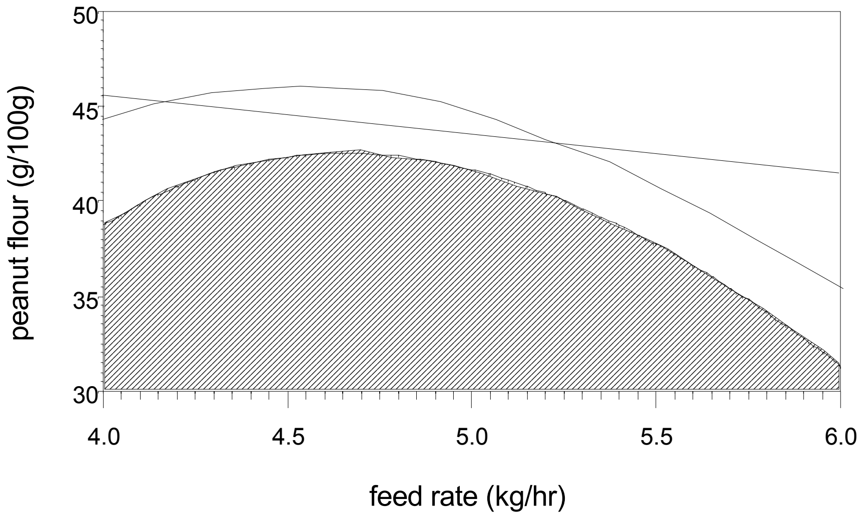


Fig 3.2. Superimposed contour plot for the consumer acceptance for the peanut-based snack products as a function of peanut flour (%) and feed rate (kg/hr). The optimum regions were bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39.0% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR

beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR. Peanut-based extruded snacks produced at these conditions will be rated 6.0 or greater for acceptance by consumers.

Verification of Optimum Area

Results of the verification are presented in Table 3.5. Results of the t-test revealed that observed values were not significantly different from the predicted value for overall liking, color, flavor, crispness, and texture at $p \leq 0.05$ for those two snack products within optimum region. The results of the snack product processed outside the optimum region, also shows that observed values were not significantly different from the predicted value, which proved this product was produced outside optimum region. However, this product may be still acceptable only for crispness by consumers because the consumer ratings for crispness were higher than 6.0 for both predicted and observed value. This results show that the predictive models can be used to optimize the formulation of ingredients and extrusion conditions to produce peanut-based snack products that are acceptable to consumers. Furthermore, this optimum area can be used to determine the range of values for descriptive sensory attributes.

Range of Values for Significant Characteristics of Peanut-Based Extruded Snack Products

Optimum consumer acceptance of a product requires the identification of a set of important sensory attributes (Schutz, 1983). Therefore, it is needed to determine the range of values for the sensory attributes of the product from descriptive sensory studies that would result in optimum consumer acceptance. The peanut-based extruded snacks

Table 3.5. Observed and Predicted values of peanut-based extruded snack products of selected formulations for verification of optimized region[a]

	acceptance scores								
	optimum						non-optimum		
	treatment[b]			treatment[c]			treatment[d]		
attributes	observed	predicted	|t|value[d]	observed	predicted	|t|value[d]	observed	predicted	|t|value[d]
overall liking	6.889	6.774	0.665	6.685	6.423	1.379	5.389	5.572	0.748
color	7.315	7.272	0.254	6.667	6.559	0.684	5.778	5.860	0.317
flavor	6.426	6.547	0.640	6.185	6.156	0.133	5.370	5.228	0.524
crispness	7.481	7.240	1.296	7.093	6.961	0.846	6.333	6.424	0.338
texture	6.963	7.079	0.592	7.056	6.812	1.264	5.944	5.930	0.053

[a]scores are based on a 9-point hedonic scale with 1=dislike extremely, 5=neither like nor dislike, 9=like extremely
[b,c] formulations processed within the optimum region: (b) PF=30%, SS=300rpm, FR=5kg/hr (c) PF=40%, SS=200rpm, FR=5kg/hr
[c]formulation processed outside the optimum region: (c) PF=50%, SS=200rpm, FR=6kg/hr
[d]critical value of |t| is 1.67.
PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

produced under the optimized conditions described previously will have acceptable appearance, color, flavor, crispness, and texture to the consumers. However, it has not been described an acceptable ranges of attributes in terms of the significant sensory characteristics in peanut-based extruded snacks products. Thus, at this point, the acceptable ranges of the descriptive sensory attributes will be described. Quantitative Descriptive Sensory Analysis (QDA) was studied for peanut-based extruded snack products in previous study: thirteen significant sensory attributes for peanut-based extruded snack products were obtained by trained panelists.

The optimum range values obtained from the consumer acceptance test were applied to the predictive models of two snack products selected from the optimum region for verification: the optimum area was bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and food rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5%PF and 6.0kg/hr FR. The ranges of values for descriptive sensory intensity are presented in Table 3.6. As the optimum area obtained from consumer acceptance test was a smooth curve, the ranges for the descriptive sensory attributes were calculated by dividing into four separated feed rate area: first area was from feed rate of 4.0-4.6kg/hr (a maximum of the curve), and 4.6-5.0kg/hr, 5.0-5.5kg/hr, 5.5-6.0kg/hr, respectively. This table includes range values which were rated 6.0 or greater for acceptance by consumers using a 9-point hedonic scales. Results shows that peanut-based extruded snack products will be rated 6.0 or greater for acceptance by consumers if, for example, the attribute brown color ranged from 58.8 to 60.2 for the first area, 60.2 to 59.0 for second area, 59.0-55.3 for third area, and 55.3 to 50.0 for fourth area. For the other 12 attributes, the acceptable ranges were shown in the

Table 3.6. Ranges of values for the significant descriptive sensory attributes of peanut-based extruded snack products that are acceptable[a] to consumers

sensory attributes	peanut flour feed rate	39.0-42.5% 4.0-4.6kg/hr	42.5-41.0% 4.6-5.0kg/hr	41.0-37.0% 5.0-5.5kg/hr	37.0-31.5% 5.5-6.0kg/hr
Appearance					
Brown color		58.78-60.22	60.22-59.01	59.01-55.34	55.34-50.04
Roughness		73.64-73.45	73.45-73.26	73.26-73.69	73.69-75.79
Porosity		88.34-86.62	86.62-87.11	87.11-89.53	89.53-88.34
Puffiness		52.02-46.74	46.74-47.76	47.76-52.55	52.55-59.75
Aromatics and Taste					
Roasted peanutty		27.12-27.65	27.65-27.47	27.47-26.8	26.8-26.11
Bitter		0.32-0.56	0.56-0.64	0.64-0.62	0.62-0.62
Texture					
Roughness		95.81-97.1	97.1-97.22	97.22-97.21	97.21-95.81
Hardness		87.89-90.9	90.9-91.45	91.45-90.52	90.52-86.78
Crispness		73.59-71.56	71.56-71.66	71.66-73.77	73.77-78.3
Crunchiness		78.32-79.1	79.1-80.0	80.0-78.91	78.91-76.12
Fracturability		63.56-66.11	66.11-66.58	66.58-66.12	66.12-64.67
Persistence of Crunchiness		74.65-77.10	77.10-77.39	77.39-76.66	76.66-74.55
Persistence of Fracturability		65.61-68.04	68.04-68.79	68.79-68.68	68.68-67.1

[a]Acceptable range to consumers was optimized with consumer acceptance test. The optimum area was bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR.

Table 3.6. Peanut-based extruded snack products that are produced with the consumer intensity ratings and the descriptive sensory scores specified in this study will be rated 6.0 or greater by consumers for acceptance.

CONCLUSIONS

A consumer acceptance test was used to investigate the effects of formulations and extrusion process conditions on peanut-based extruded snack products. Predictive models were developed for overall liking, color, flavor, crispness, and texture. The optimum formulations and extrusion processing conditions were determined for the manufacturing of peanut-based snack products. The optimum area was bound by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR. A snack product processed within these boundaries will obtain an acceptance rating of 6.0 by consumers. Verification trials revealed that those samples processed within the optimum region would be acceptable (≥ 6.0) to consumer.

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SECTION IV

SENSORY PROFILES OF AN EXTRUDED SNACK PRODUCT BASED ON PEANUT FLOUR AND RICE FLOUR

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ABSTRACT

A mixture of peanut flour (12% fat) and rice flour was extruded to produce indirectly, puffed extrudates, and dried to obtain half-products with 11-12% moisture contents. The half-products were expanded by deep-fat frying to give the final texture to snack products. Three factors at three levels each were studied: peanut flour (30, 40, and 50%), screw speed (200, 300, and 400rpm), and feed rate (4, 5, and 6kg/hr). Descriptive sensory analysis of the peanut-based extruded snack products was conducted to measure overall sensory profiles. The level of peanut flour, screw speed, and feed rate affected sensory attributes. The most characteristics of sensory attributes were brown color, roughness, porosity, and puffiness for appearance, roasted peanutty and bitter for aromatics and taste, and roughness, hardness, crispness, crunchiness, fracturability for texture.

INTRODUCTION

According to a recent public survey, nearly three-quarters (73%) of 1,017 adults in U.S. are snacking at least once a day, a quarter (23%) of those surveyed said they snack a few times a week, and only 4% never snack at all (Jones, 2000). In 1998 a Gallup study of American Snacking Behavior found that the most common motivation for snacking are to satisfy hunger between meals and to satisfy one's sweet tooth. More than 30% of the calories Americans consume today are in the form of snacks (Wikes, 2000).

Savory snacks are mainly classified into three generations based on the chronology of their introduction. The first-generation snacks refer to conventional potato chips and baked crackers. Second-generation snacks referred to as collets are direct expanded snack products, which are extruded with a low moisture extrusion (<15%). Once extruded, the collets are dried to lower than 4% and can be coated with flavors. Third-generation snacks referred to as semi-, half-, or intermediate- are pellets, which are cooked and formed by extrusion processing. The pellets are dried and are ready to be consumed after frying in hot oil or puffing in a hot air stream, which contribute to the final texture (Sunderland, 1996). Extrusion processing in producing third-generation snacks has become the standard operating system in most snack food industries. Extrusion cooking is a high-temperature, short-time process that combines the operations of feed transport, mixing, working, and forming in an efficient way to transform raw ingredients into intermediate and finished products (Harper, 1989).

Peanuts are considered as an oilseed crop grown primarily for oil production. In the United States, about 60% of the peanut production goes into domestic food use, the end products being peanut butter, salted roasting products, confectioneries, and snack foods

(Ahmed and Young, 1982). Peanut is a good source of supplementary protein and is used to produce widely accepted food products (Matz, 1993), and after oil extraction process, a protein-rich peanut flour as a by-product may be added as an ingredient in extrusion products.

Sensory evaluation techniques have been used by several researchers to evaluate the relationship among the sensory attributes (Bower and Whitten, 2000; Ward and Resurreccion, 1998), the effects of water sorption on texture (Waichungo et al., 2000), and the relationship between selected sensory and physical variables (Duizer and Campanella, 1998; Faller and Heymann, 1996) on end-product quality of snack type foods. Descriptive analysis is generally useful in any situation where a detailed specification of the sensory attributes of a single product or a comparison among several products is desired (Gillette, 1984). Among different types of descriptive analysis technologies, Quantitative Descriptive Analysis (QDA) techniques have been used to measure the sensory attributes in many studies. In Quantitative Descriptive Analysis (QDA) techniques, trained individuals identify and quantify, in order of occurrence, the sensory properties of a product (Stone, H. et al., 1974), and unstructured line scales are used to describe the intensity of rated attributes (Lawless and Heymann, 1999). These methods can be used for evaluating aroma, flavor, appearance, and texture (Meullenet et al., 1998). Descriptive analysis has been used to describe sensory attributes for various peanut and peanut products such as cracker-coated peanuts (Walker and Resurreccion, 2000), extruded peanut snacks formulated with tapioca-based starch (Suknark et al., 1998), and roasted defatted peanuts (Plemmons and Resurreccion, 1998). Sensory descriptive analysis of a product allows the researcher to delineate all the perceived features of the product, and understand better consumer hedonic responses to the products (Faller and Heymann, 1996). Results from descriptive analysis provide a complete sensory description of an array of products and can provide a basis for distinguishing those sensory attributes that are important for acceptance by consumers (Stone and Sidel, 1993).

The objective of this study was to characterize the significant descriptive sensory attributes of peanut-based extruded snack products varying in formulations and extrusion processing conditions.

MATERIALS & METHODS

Materials

A mixture of peanut and rice flour was blended at three levels of peanut flour (30, 40, and 50%) to rice flour using a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY), and was extruded at three levels of feed rate (4, 5, and 6kg/hr) and screw speed (200, 300, and 400rpm) in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England). The temperature profiles of the extruder barrels was set to be 100, 120, 110, 95, and 80ºC from feed zone to die. The barrel temperatures of zone four and five was set blow 100ºC to prevent puffing of extrudates. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. Half-products were puffed by deep-fat frying at 200 ± 5ºC for 35-40sec in pure vegetable oil (The detailed procedure to produce half-products and final snack products is in Section II).

Sample Preparation

The half-products with 11-12% moisture content were sealed in Ziploc® bags, and stored in a cold room at 5˚C. The puffed snack samples were prepared the day before the test day by deep-fat frying in vegetable oil. Ten or twelve pieces of snack samples were placed and sealed in snack size Ziploc® bag (Johnson & Son, Inc., Racine, WI) coded with three-digit random numbers.

Quantitative Descriptive Analysis (QDA)

Descriptive Analysis Panels: The panels consisted of eight panelists previously trained on descriptive sensory analysis of peanut products and two participants with no prior descriptive sensory analysis experience. All panelists were recruited on the basis of the following criteria: no any food allergies (especially peanut), natural dentition, non-smokers, snacking at least once a week, available for all sessions, interested in participating, verbal ability to define and describe various characteristics of products (ASTM 1981). Potential panelists with no prior descriptive experience were recruited from the local area near Griffin, GA and scheduled for a screening test that consisted of two sections, a taste test and an aroma acuity test. In the taste test, potential panelists were tested on the basis of their ability to recognize the four basic taste solutions (sweet, salt, sour, and bitter) in 5 minutes (Plemmons and Resurreccion, 1998). In the aroma test, panelists were asked to correctly identify 5 of 7 aromatics in 10 minutes, including banana, anise, pineapple, orange, vanilla, peppermint, and lemon aromatics in seven 120 ml glass bottles by taking quick, short sniffs (Rutledge and Hudson, 1990). Panelists were required to complete and sign a consent form approved by the University of Georgia Institutional Review Board prior to participating in the training and testing sessions. An honorarium of twelve dollars per session was provided at the conclusion of the test to the panelists.

Panel training: New panelists participated in an additional two days of training prior to the training sessions, which included all panelists. During the two days, new panelists were given an overview of sensory evaluation and an introduction to the use of the computers to be used for data collection. The panelists were presented with standard solutions of sucrose, sodium chloride, citric acid, and caffeine corresponding to points on a 150-mm unstructured line scale for sweet, salty, sour, and bitter taste, respectively (Plemmons and Resurreccion, 1998). Pop-up scales corresponding to 150-mm unstructured lines with anchors at the 12.5 and 137.5 mm points, corresponding to weak and strong, respectively were used.

Ten panelists (2 males and 8 females) participated for evaluation of peanut-based extruded snacks. The training was conducted in one 2hr training session per day for seven days (total of 14 hrs). Panelists were trained on descriptive analysis test procedures as described by Meilgaard et al. (1991). Panelists evaluated samples using a "hybrid" descriptive analysis method (Einstein, 1991), a combination of the Quantitative Descriptive Analysis (QDA®) (Tragon corp., Redwood city, CA. USA) and the Spectrum™ Analysis methods (Sensory Spectrum, Inc., Chatham, NJ. USA). QDA allows panelists to work together to develop the languages to describe perceptible attributes and quantify attribute intensities (Einstein, 1991). The Spectrum method allows panelists to identify the perceptible sensory attributes and all intensities are reported relative to universal scales that enable comparisons not only within product groups but among all products tested (Einstein, 1991). On the first day of training all 10 panelists worked together to develop the language to describe the perceptible product attributes for the peanut-based extruded snack products. Panelists identified appearance, aromatics, taste, and texture terms for the snack samples. A list of attributes and definitions previously used and published to describe snack type products, were presented to panelists as a reference standard. Reference standards help panelists develop terminology to properly describe products, help determine intensities, document terminology, identify important characteristics to characterize product quality, shorten training time, and provide useful discussion tools to be used for research and development, product maintenance and optimization, and cost reduction plans (Rainey, 1986). During this process panelists decided on a final list of attributes that were comprehensive definitions agreed by all panelists and that included five appearance, seven flavor, and ten texture attributes (Table 4.1).

Panelists rated reference standards representing each of the attributes of appearance, flavor, and texture and their intensity ratings for use during testing. Each panelist rated the attribute intensity of each reference by first evaluating the reference for particular attributes and then giving intensity rating between 0 and 150 using flashcards. Panelists were presented with their individual and panels mean scores. If individual scores were 10mm above or below the panel mean scores, panelists were considered uncalibrated. Those panelists who did not rate within 10mm points of the average were asked to reevaluate and adjust their rating until a consensus was reached. The mean intensity rating was calculated and used as the attribute intensity rating for that particular reference (Table 4.2). Two references for each attribute were rated as low and high intensity. To represent an intermediate attribute intensity level for all attributes, the snack sample

Table 4.1. Definition of terms used to rate to evaluate peanut-based extruded snacks

Attributes	Definitions
Appearance	
Brown color[1]	The intensity or strength of brown color from light to dark brown
Roughness[5]	The appearance associated with uneven surface
Porosity[7,8]	The degree of airiness on the surface of the product
Dryness[4]	The lack of moistness (wetness and oiliness) on the surface of sample
Puffiness	The degree of expansion of sample
Aromatics	
Roasted peanutty[2]	The aromatic associated with medium-roasted peanut
Multi grainy[4]	The aromatic associated with toasted grain
Oil flavor[4]	The aromatic associated with vegetable oil
Burnt	The aromatic associated with overcooked (overtoasted) grains/peanuts
Taste	
Sweet[2,3]	The taste on the tongue associated with sugars
Salty[2]	The taste on the tongue associated with salt
Bitter[2,3]	The taste on the tongue associated with caffeine
Texture	
Prior to mastication	
Oiliness[4]	The amount of oiliness on surface of snacks
Roughness[6]	The degree of abrasiveness of the surface of snacks as perceived by the tongue
First bite	
Hardness[4]	The force required to bite down the snacks
Crispness[5]	The force required and intensity of sound (high pitch) generated from biting the snacks with incisors
First chew	
Crunchiness[5,6]	The force needed and intensity of sound (low pitch) generated from biting the snacks with molar teeth
Fracturability[1]	The force with which a sample crumbles, cracks, or shatters

Table 4.1. Continued

Attributes	Definitions
Chew down	
Persistence of crunchiness[1]	Degree to which sample remains crunchy throughout chew
Persistence of facturability[1]	Degree to which sample retains force with which a sample crumbles, cracks, or shatters
Residual	
Oily mouthfeel[4]	Degree to which mouth feels fatty/greasy
Tooth pack[9]	Amount of product packed into the crowns of teeth after mastication

[1]Gills and Resurreccion (2000)
[2]Johnson et al. (1988)
[3]Muego and Resurreccion (1992)
[4]Meilgaard et al. (1991)
[5]Ward (1995)
[6]Plemmons and Resurreccion (1998)
[7]Duizer et al. (1998)
[8]Hu et al. (1996)
[9]Meullenet et al. (1999)

Table 4.2. Standard references and intensities for attributes used to evaluate peanut-based snack products

Attributes	References	Intensity[a] (mm)
Appearance		
Brown color	corrugated cardboard (L*=57.99, a*=7.47, b*=25.38) (Safco Products Company, New Hop, MN)	45
Roughness	orange peel (peel from fresh orange, ½ in. piece) (Waverly Growers co., Waverly, FL)	50
	Natural valley granola bars oats' N honey (General mills, Inc., Minneapolis, MN)	120
Porosity	Dr. Scholls pedicure beauty stone (Healthcare products, Inc., Memphis, TN)	120
Dryness	Triscuit (Nabisco, Inc., East Hanover, NY)	93
Puffiness	Baked cheese balls (The Kroger co., Cincinnati, Ohio)	120
Aromatics		
Roasted peanutty	Planter's dry roasted peanuts[1] (Nabisco, Inc., East Hanover, NY)	75
Multi grainy	Triscuit[1] (Nabisco, Inc., East Hanover, NY)	80
Oil flavor	Lay's potato chips[2] (Frito-Lay, Inc., Plano, TX)	20
	Heated vegetable oil[2] (The Kroger Co., Cincinnati, Ohio)	55
Burnt	Dark roasted peanuts	30
Taste		
Sweet	2.0% sucrose in double deionized water	20
	5.0% sucrose in double deionized water	50
	10.0% sucrose in double deionized water	100
	16.0% sucrose in double deionized water	150
	(Dixie Crystals Savannah Foods & Industries, Inc.)	

Table 4.2. Continued

Attribites	Definitions	Intensity[a] (mm)
Salty	0.2% NaCl in double deionized water	25
	0.35% NaCl in double deionized water	50
	0.5% NaCl in double deionized water	85
	(Fisher Scientific, Fairlawn, NJ)	
Bitter	0.05% caffeine in double deionized water	20
	0.08% caffeine in double deionized water	50
	0.15% caffeine in double deionized water	100
	(Fisher Scientific, Fairlawn, NJ)	
Texture		
Prior to Mastication		
Oiliness	Pringles original potato chips[2]	40
	(Procter & Gamble, Cincinnati, Ohio)	
	Heated vegetable oil[2]	150
	(Crisco, Procter & Gamble, Cincinnati, Ohio)	
Roughness	Pringles original potato chips[1,2]	80
	(Procter & Gamble, Cincinnati, Ohio)	
	Natures valley granola bars oats' N honey[1,2]	120
	(General Mills Sales, Inc., Minneapolis, MN)	
First Bite		
Hardness	Frankfurters (cooked 5 min.)	70
	(Hebrew National Kosher Foods, Bronx, NY)	
	Blue diamond almond	110
	(Blue Diamond Growers, Sacramento, CA)	
Crispness	Original corn chips[2]	70
	(Frito-Lay, Inc., Plano, TX)	
	Frito-Lay potato chips[2]	150
	(Frito-Lay, Inc., Plano, TX)	
First chew		
Crunchiness	Original corn chips[2]	75
	(Frito-Lay, Inc., Plano, TX)	
Fracturability	Graham crackers[1] (1/2 in. square)	42
	(Keeble Company, Elmhurst, IL)	
	Ginger snaps[1] (1/2 in. square)	80
	(Nabisco, Inc., East Hanover, NY)	

Table 4.2. Continued

Attribites	Definitions	Intensity[a] (mm)
Chew down		
Persistence of Crunchiness	Original corn chips[2] (Frito-Lay, Inc., Plano, TX)	75
Persistence of fracturability	Graham crackers[1] (Keeble Company, Elmhurst, IL)	42
	Ginger snaps[1] (Nabisco, Inc., East Hanover, NY)	80
Residual		
Oily mouth feel	Pringles original potato chips (Procter & Gamble, Cincinnati, Ohio)	40
Tooth pack	Graham crackers[1] (Keeble Company, Elmhurst, IL)	75
	JuJubes[1] (Henry Heide, Inc., Hershey, PA)	150

[a]rated on a 150-mm unstructured line scale with anchors at 12.5mm and 137.5mm
[1]Meilgaard et al. (1991)
[2]Ward (1995)

extruded at 40 % peanut flour, screw speed of 300 rpm, and feed rate of 5 kg/hr was selected as the warm-up sample. A warm-up sample is a sample given to a panelist prior to evaluation of test samples and typically represents the product being tested. A warm-up sample has been used to augment descriptive analysis training and testing in hopes of achieving more reliable results from the panel. Intensity scores for warm-up samples were obtained by taking the average of individual panelist ratings for each attribute. Warm-up sample intensity score for each attribute are presented in Table 4.3. Calibration of the panel continued from the fourth session to the last training session. Individual panelist's rating in practice sessions during training were analyzed for mean ratings and standard deviations after each training session, and results were distributed to each panelist prior to the next practice session to provide feedback on their performance.

Ballots: Panelists evaluated samples using computerized ballots using an unstructured 150-mm intensity line scale with anchors at 12.5mm and 137.5mm. Data were collected using Compusense Five Sensory Analysis Software of Windows (Version 2.2, Compusense, Inc., Guelph, Canada). The intensity scores of two selected reference standards (low and high intensity) and warm-up sample for each attribute indicated on the computerized ballot were presented to each panelist. Panelists responded by marking their evaluation of attributes for each sample on the line scale. For each sample, eleven attributes were presented on the first page, and the other eleven attributes were presented on the second page on the monitor screen.

Test Procedure: The test was conducted in an environmentally controlled sensory laboratory with partitioned booths illuminated with two 50W indoor reflector flood lamps. The snack samples were prepared the day before the test day. Ten to twelve

Table 4.3. Warm-up sample intensity ratings

Attributes	Warm-up sample intensity[a]
Appearance	
Brown color	60
Roughness	75
Porosity	90
Dryness	100
Puffiness	53
Aromatics	
Roasted peanutty	26
Multi grainy	40
Oil flavor	16
Burnt	0
Taste	
Sweet	10
Salty	25
Bitter	0
Texture	
Prior to mastication	
Oiliness	26
Roughness	97
First bite	
Hardness	85
Crispness	78
Frist chew	
Crunchiness	80
Fracturability	60
Chew down	
Persistence of crunchiness	75
Persistence of fractrurability	65
Residual	
Oily mouthfeel	27
Tooth pack	73

[a]snsory ratings based on 150-mm unstructured line scales. Intensity scores were agreed upon by consensus by the descriptive panel during the training.

pieces of snack samples were placed and sealed in snack size Ziploc® bag (Johnson & Son, Inc., Racine, WI) coded with three-digit random numbers. Central Composite experimental Design (CCD) was applied to select 15 samples out of total 27 treatment combinations, which were the same treatments used for consumer acceptance testing. Samples were tested using a complete randomized block design so that all panelists evaluated all the treatment combinations in CCD design (Lawless and Heymann, 1998). The order of the snack samples was randomized for each panelist and each trained panelist rated 22 attributes for two times in total of 15 samples in a balanced sequential monadic order. Four samples were evaluated during each session for a total of 12 samples, which were three sessions in one day using a computerized ballot described on the above. A compulsory three minutes break was taken between each session. The panelists were provided with reference standards, unsalted crackers (Premium Saltine Crackers, Nabisco, Inc., East Hanover, NY), water, and cups for expectoration. Panelists were instructed to expectorate evaluated sample and eat some unsalted cracker then rinse with water after each sample.

Statistical Analysis and Modeling

All analyses were performed using Statistical Analysis System (SAS Institute, Inc., 1988). Outliers were determined by using Cluster analysis (PROC VARCLUS) (Powers, 1984). Responses of one panelist who was found to be an outlier was deleted. Subsequent data analyses were performed on responses from the remaining nine panelists. A quadratic regression model was fitted to the data using regression analysis (PROC REG) to determine the behavior of the response variables in relation to the set of independent factors (peanut flour, screw speed, and feed rate): the significant variables were determined at 10% level of significance. Those significant variables determined from regression procedure (full model) were subjected to stepwise regression analysis (PROC STEPWISE) to determine the final reduced models. Linear terms were retained in the model when a quadratic or a cross-product term involving that linear term met the above criterion.

Multiple regression analysis (PROC REG) was used to finalize the models (reduced model) after significant factors for each variable were determined from the stepwise procedure. The F-statistic was calculated, and the full and reduced models were compared with the appropriate tabular value at α=0.10 (Swindell, 1970).

$$F = \frac{(SSE^{*} - SSE) / (df^{*} - df)}{SSE / df}$$

where, SSE^{*} = sum of squares for error for reduced model
SSE = sum of squares for error for full model
df^{*} = degrees of freedom for reduced model
df = degrees of freedom for full model

If F –value exceeds the tabular value then the reduced model is significantly different from the full model at $\alpha = 0.10$ and, probably should not used. Otherwise, the reduced model is not significantly different from the full model at $\alpha = 0.10$ and, therefore, was used to predict a particular response variable. Therefore, the final reduced model was one that was not significantly different from the full model at the α=0.10 as determined by the F-statistic.

RESULTS & DISCUSSION

Quantitative Descriptive Analysis (QDA) Measurements

The descriptive sensory analysis provides a basis for determining the sensory characteristics important for both the acceptability and processing conditions required to achieve a consistent quality peanut-based snack products. Specific ingredients or extrusion process conditions could be related to specific changes in the sensory characteristics of a product.

Appearance: Mean intensity ratings of descriptive attributes for appearance is shown in Table 4.4. The attribute of brown color received intensity ratings that ranged from 42.4 to 67.5. The lowest rating was given to the product extruded with peanut flour (PF) of 30% at screw speed (SS) of 300rpm and feed rate (FR) of 5kg/hr, and the highest rating to that 50% PF extruded 200rpm SS and 6kg/hr FR. The intensity rating for the attribute roughness ranged from 73.4 to 82.6. The lowest rating was given to the product extruded with 40% PF at 300rpm SS and 4kg/hr FR. Whereas, the product extruded with 50% PF at 200rpm SS and 6 kg/hr FR obtained the highest intensity ratings on roughness. The intensity of porosity was ranged from the lowest rating of 85.3 (50% PF, 400rpm SS, 4kg/hr) to the highest of 101.1 (30% PF, 400rpm SS, 4kg/hr FR). There is a little difference between the snack products extruded with different ratios of peanut flour and extrusion conditions on the attribute of dryness. For the puffiness, the product obtained the lowest ratings (39.1) was given to the product of 50% PF extruded at 400rpm SS and 4kg/hr FR, whereas the highest ratings (78.2) was given to that 30% PF extruded at 400rpm SS and 4kg/hr FR. These two products were the same products that obtained the same lowest and highest ratings on porosity.

Table 4.4. Mean intensities of descriptive sensory analysis for appearance

formulation			mean intensity of sensory attributes[a]				
PF	SS	FR	brown color	roughness	porosity	dryness	puffiness
30	200	4	44.04(7.08)f	78.66(6.97)abcd	95.58(19.63)abc	95.21(12.41)ab	71.26(15.04)ab
30	200	6	43.39(7.5)f	79.76(8.59)abcd	99.27(9.9)ab	98.64(7.36)a	64.95(15.64)b
30	300	5	42.37(6.01)f	81.04(10.25)ab	100.54(11.65)a	97.84(7.56)a	76.42(22.43)a
30	400	4	47.39(14.4)ef	78.0(10.21)abcde	101.11(10.66)a	91.57(19.58)b	78.21(23.28)a
30	400	6	49.84(9.73)e	76.36(5.79)bcde	96.26(8.18)abc	96.71(6.47)ab	65.46(11.22)b
40	200	5	56.82(6.55)d	75.87(2.95)cde	92.24(6.12)bcd	97.94(4.84)a	55.17(14.10)c
40	300	4	60.80(5.98)bcd	73.38(7.69)e	90.05(5.19)cd	95.95(6.33)ab	53.91(16.0)cd
40	300	5	58.88(6.29)cd	75.78(4.01)de	91.44(6.2)cd	98.64(5.38)a	53.16(5.48)cd
40	300	6	60.35(2.82)bcd	77.0(3.77)bcde	92.3(3.19)bcd	98.88(2.83)a	52.96(7.57)cd
40	400	5	58.68(5.68)cd	77.84(6.19)abcde	87.45(9.21)d	98.08(4.79)a	44.71(9.51)cde
50	200	4	65.62(5.51)ab	80.91(4.52)abd	90.51(9.58)cd	99.45(3.4)a	46.13(8.83)cde
50	200	6	67.53(5.66)a	82.57(6.22)a	91.95(13.58)cd	96.62(5.5)ab	51.01(16.15)cd
50	300	5	66.29(5.53)a	77.96(6.78)abcde	88.79(8.22)cd	98.17(4.65)a	43.96(7.63)de
50	400	4	65.18(5.61)ab	77.38(4.43)bcde	85.28(6.74)d	99.84(3.99)a	39.05(9.97)e
50	400	6	63.46(7.95)abc	75.09(2.85)de	87.33(5.49)d	97.87(5.24)a	47.49(8.77)cde

[a]numbers in parentheses refer to standard deviation
mean values in the same column not followed by the same letter are significantly different at $p \leq 0.05$
PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

Aromatics and Taste: Mean intensity ratings of aromatics and taste are shown in Table 4.5. Panelist intensity ratings for roasted peanutty ranged from the lowest of 23.97 (30% PF, 400rpm SS, 4kg/hr FR) to the highest of 31.24 (50% PF, 200rpm SS, 4kg/hr FR). A slight change in intensity ratings was found in oil flavor. The intensity ratings of burnt and bitter ranged from 0.3 to 3.1 and from 0.3 to 2.1, respectively. However, for burnt and bitter, the intensity ratings were less than 10.00 that indicated those attributes were barely detectable. Whereas, there were no significant differences in intensity ratings between snack products on multi-grainy, sweet, and salty.

Texture: Among the "sensory acceptability factors" that are appearance, flavor, and texture, texture is certainly the most important descriptor to qualify snack like food products (Bourne, 1982). The mean intensity ratings for texture are shown in Table 4.6. The intensity ratings of hardness ranged from 70.7 to 93.3: the lowest rating was given to the product of 30% peanut flour extruded at 400rpm screw speed and 4kg/hr feed rate, whereas the highest rating to the product of 40% PF, 400rpm SS, and 5kg/hr FR. The intensity ratings of crispness and crunchiness were the opposite, which means that the higher intensity of crispness given to the 30% peanut flour products, but lower intensity of crunchiness to the same group of products. The maximum intensity of crispness was given to the product extruded with 30% peanut flour at 400rpm screw speed and 4kg/hr feed rate. On the other hand, the maximum intensity of crunchiness was given to the product of 40% PF, 400rpm SS, and 5kg/hr FR. The intensity of roughness and fracturability ranged from 89.4 to 100.0 and from 54.1 to 68.5, respectively. For the persistence of crunchiness and fracturability, the intensity ranged from 62.8 to 79.5 for

Table 4.5. Mean intensities of descriptive sensory analysis for aromatics and taste

formulations			mean intensity of sensory attributes[a]						
			aromatics				taste		
PF	SS	FR	roasted-peanutty	multi-grainy	oil flavor	burnt	sweet	salty	bitter
30	200	4	25.59(4.78)bc	37.01(8.07)a	21.41(5.92)a	0.58(0.37)cd	11.3(3.59)a	23.66(4.09)a	0.73(1.05)bc
30	200	6	25.66(4.07)bc	37.81(6.4)a	18.71(6.19)ab	0.49(0.4)cd	10.88(4.32)a	23.07(4.55)a	0.58(0.37)bc
30	300	5	26.72(4.95)bc	36.38(6.6)a	18.96(6.27)ab	0.44(0.41)d	11.01(3.68)a	22.99(4.69)a	0.44(0.41)c
30	400	4	23.97(5.22)c	35.75(6.21)a	18.26(3.38)ab	0.27(0.39)d	12.33(5.94)a	22.13(4.93)a	0.49(0.4)c
30	400	6	26.81(7.12)bc	36.82(5.66)a	19.84(7.58)ab	0.4(0.41)d	10.92(4.92)a	23.05(3.57)a	0.89(1.66)abc
40	200	5	26.81(3.05)bc	36.85(5.4)a	18.02(3.9)ab	0.82(1.72)cd	10.23(5.12)a	23.84(3.21)a	0.77(1.07)bc
40	300	4	26.96(3.7)bc	37.71(4.82)a	16.92(3.14)b	0.36(0.41)d	11.22(2.65)a	23.89(3.92)a	0.56(0.62)bc
40	300	5	26.38(4.15)bc	36.76(4.07)a	18.36(4.67)ab	0.82(1.76)cd	12.59(5.6)a	24.32(3.74)a	0.53(0.46)c
40	300	6	26.37(3.17)bc	35.74(6.16)a	16.31(1.78)b	0.4(0.41)d	10.55(3.37)a	23.01(3.95)a	0.77(1.0)bc
40	400	5	29.11(6.59)ab	37.8(6.83)a	17.62(4.72)ab	1.11(1.68)cd	10.79(4.71)a	23.58(4.86)a	0.43(0.59)c
50	200	4	31.24(7.92)a	38.42(4.93)a	17.59(3.43)ab	2.07(3.19)abcd	9.92(3.01)a	23.08(4.46)a	0.98(1.49)abc
50	200	6	28.73(4.41)ab	39.49(6.06)a	18.84(5.84)ab	2.84(5.09)ab	9.33(4.54)a	23.41(3.5)a	2.06(3.12)a
50	300	5	28.12(8.76)abc	40.08(8.74)a	19.04(5.36)a	3.11(5.2)a	10.32(5.17)a	23.62(4.05)a	1.64(3.12)abc
50	400	4	29.75(6.02)ab	37.88(5.63)a	18.72(5.45)ab	1.7(2.2)abcd	10.66(5.06)a	24.28(3.98)a	0.66(0.53)bc
50	400	6	28.29(5.06)abc	37.5(5.64)a	18.71(4.54)ab	2.35(3.41)abc	10.72(4.16)a	22.89(3.55)a	1.81(3.21)ab

[a]numbers in parenthesis refer to standard deviation
mean values in the same column not followed by the same letter are significantly different at $p \leq 0.05$
PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

Table 4.6. Mean intensities of descriptive sensory analysis for texture

formulation			mean intensity of sensory attributes[a]				
PF	SS	FR	hardness	crispness	crunchiness	roughness	fracturability
30	200	4	76.07(9.70)d	84.25(6.4)ab	72.71(5.73)c	95.46(7.16)b	57.99(6.84)ef
30	200	6	81.37(5.44)c	81.83(5.66)cde	76.79(5.9)bc	97.37(5.66)ab	59.13(4.82)de
30	300	5	75.12(7.28)d	86.49(9.24)ab	75.53(7.46)c	95.63(5.1)b	60.88(7.89)cde
30	400	4	70.70(8.33)e	88.04(11.07)a	68.32(13.71)d	89.37(8.19)c	54.13(12.1)f
30	400	6	83.87(7.31)bc	82.9(9.62)abc	76.81(7.36)c	95.55(8.19)b	64.62(5.57)abc
40	200	5	86.03(4.9)bc	76.78(3.87)de	81.84(4.9)a	97.27(3.66)ab	61.92(3.57)bcde
40	300	4	86.62(5.17)b	78.92(4.44)cde	82.8(5.51)a	97.52(4.25)ab	63.34(5.16)bcd
40	300	5	86.71(3.42)b	77.43(3.42)de	81.81(4.81)a	95.47(5.15)b	63.63(4.75)bcd
40	300	6	85.78(4.92)bc	77.83(5.03)cde	81.87(3.03)a	97.34(2.18)ab	63.08(4.31)bcd
40	400	5	93.32(6.54)a	74.34(10.23)e	85.54(4.69)a	96.38(4.82)ab	68.46(7.26)a
50	200	4	84.87(6.08)bc	76.57(7.79)de	82.41(4.75)a	98.86(4.81)ab	65.46(5.64)abc
50	200	6	87.25(4.49)b	77.33(8.62)de	84.83(5.91)a	100.04(4.23)a	66.01(4.89)ab
50	300	5	83.97(7.7)bc	76.34(6.32)de	82.56(5.51)a	96.28(4.86)ab	62.51(4.78)bcde
50	400	4	85.92(6.42)bc	77.21(7.92)de	81.08(4.46)ab	97.38(4.45)ab	62.66(6.3)bcd
50	400	6	85.87(6.49)bc	75.53(6.15)e	81.41(6.36)a	95.51(7.02)b	64.3(4.0)abc

[a]numbers in parentheses refer to standard deviation
mean values in the same column not followed by the same letter are significantly different at $p \leq 0.05$
PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

Table 4.6. Continued

formulation			mean intensity of sensory attributes[a]				
PF	SS	FR	oiliness	persistence of crunchiness	persistence of fracturability	oily mouthfeel	tooth pack
30	200	4	27.29(7.56)a	70.47(8.12)de	59.72(8.85)e	29.41(5.56)a	72.58(5.46)a
30	200	6	26.07(4.88)a	71.59(5.84)cde	61.24(6.29)cde	25.47(3.92)bc	73.58(3.85)a
30	300	5	27.74(6.81)a	69.17(9.04)e	60.74(9.77)de	26.53(4.85)abc	75.14(5.1)a
30	400	4	28.17(8.15)a	62.79(15.6)f	54.41(17.02)f	26.58(5.33)abc	75.09(3.51)a
30	400	6	28.76(6.06)a	75.21(6.71)abc	66.27(4.46)abcd	28.46(5.75)abc	73.71(5.24)a
40	200	5	28.39(8.53)a	75.75(3.3)abc	64.23(4.44)abcde	29.25(9.22)ab	72.07(3.17)a
40	300	4	26.16(3.45)a	76.26(3.59)abc	65.2(4.54)abcde	26.22(2.58)abc	74.76(3.62)a
40	300	5	26.26(3.64)a	76.64(3.72)ab	65.11(3.91)abcde	26.49(2.32)abc	74.26(3.66)a
40	300	6	26.3(3.72)a	75.78(3.63)abc	67.79(7.1)a	25.33(3.92)c	72.29(1.96)a
40	400	5	27.67(5.03)a	79.54(3.76)a	67.74(6.0)a	26.53(3.92)abc	74.83(3.2)a
50	200	4	28.41(8.17)a	77.4(4.95)ab	66.58(6.42)abc	26.53(2.8)abc	74.97(4.78)a
50	200	6	27.16(4.6)a	76.69(4.09)ab	67.08(4.14)ab	27.23(1.84)abc	73.83(5.66)a
50	300	5	25.96(4.66)a	76.83(3.09)ab	65.61(4.53)abcd	27.08(4.64)abc	72.54(5.16)a
50	400	4	27.13(3.01)a	74.33(3.73)bcd	61.66(7.14)bcde	28.47(4.82)abc	75.33(6.91)a
50	400	6	28.16(12.92)a	75.63(3.0)abc	65.17(4.88)abcde	27.8(5.47)abc	74.55(3.75)a

[a]numbers in parentheses refer to standard deviation
mean values in the same column not followed by the same letter are significantly different at $p \leq 0.05$
PF = peanut flour (%) SS = screw speed (rpm) FR = feed rate (kg/hr)

persistence of crunchiness and from 54.1 to 67.8 for persistence of fracturability. There was no significant difference of intensity ratings for oiliness and tooth pack.

ANOVA summary on Sensory Profiles of Peanut-Based Extruded Snack Products

Appearance: Table 4.7 shows the analysis of variance (ANOVA) for the overall effects of the fomulation and processing factors on descriptive attributes for appearance, which are brown color, roughness, porosity, dryness, and puffiness. The attributes of brown color, roughness, porosity, and puffiness were found to be significant at 1% level of significance. The linear term of peanut flour was found to be significant on the attributes of brown color and puffiness at $p \leq 0.01$, and on the roughness at $p \leq 0.05$. The attributes of porosity and puffiness had a significant linear effect of screw speed at $p \leq 0.05$. The brown color also had a significant effect of feed rate at $p \leq 0.05$. There were a significant quadratic effect of peanut flour on attributes of brown color, roughness, porosity, and puffiness at $p \leq 0.01$. In addition, the quadratic effect of feed rate had a significant effect on brown color at $p \leq 0.05$. The porosity had an interaction effect of peanut flour and screw speed, and screw speed and feed rate at $p \leq 0.10$. Among the five appearance attributes, dryness had no effects of peanut flour, screw speed, and feed rate at 10% level of significance.

Aromatics and Taste: Table 4.8 shows the analysis of variance (ANOVA) of descriptive attributes for aromatics and taste, which are roasted peanutty, multi-grainy, oil flavor, burnt for aromatics and sweet, salty, and bitter for taste. The attributes of roasted-peanutty and bitter were found to be significant at 1% and 5% level of significance, respectively. The linear effect of peanut flour was found to be significant on the roasted

Table 4.7. Analysis of variance for the overall effects of the variables for the appearance in sensory descriptive attributes

	regression coefficients				
variables	brown color	roughness	porosity	dryness	puffiness
Intercepts	20.197	88.710	65.442	51.231	189.638
PF	3.746***	-2.384**	-1.393	0.887	-6.614***
SS	-0.047	0.003	0.408**	-0.065	0.521**
FR	-30.595**	12.643	14.89	13.053	-6.245
PF × PF	-0.042***	0.03***	0.035***	-0.005	0.073***
SS × SS	---	---	---	---	---
FR × FR	2.165**	-1.166	-0.007	-0.792	0.546
PF × SS	0.002	---	-0.007*	0.001	-0.009
PF × FR	0.233	0.044	-0.285	-0.136	0.03
SS × FR	0.033	-0.002	-0.056*	0.007	-0.054
PF × SS × FR	-0.001	---	0.001	---	0.001
F-ratio for total regression	38.229***	2.426***	6.368***	1.566	19.04***

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$
PF = peanut flour (%)
SS = screw speed (rpm)
FR = feed rate (kg/hr)

Table 4.8. Analysis of variance for the overall effects of the variables for the aromatics and taste in sensory descriptive attributes

	regression coefficients						
	aromatics				taste		
variables	roasted-peanutty	multi-grainy	oil flavor	burnt	sweet	salty	bitter
intercepts	20.446	43.077	90.902	4.64	0.01	34.772	14.07
PF	0.173*	-0.797	-2.699	-0.713	0.222	-0.275	-0.464*
SS	-0.11	-0.044	-0.203	-0.014	0.065	-0.091	-0.013
FR	3.982	3.503	-3.44	3.674	1.722	-1.504	-2.166
PF × PF	0.002	0.008	0.017	0.008	-0.001	-0.004	0.004
SS × SS	---	---	---	---	---	---	---
FR × FR	-0.475	-0.502	-0.724	-0.477	-0.01	-0.272	0.047
PF × SS	0.001	0.001	0.004	---	-0.001	0.002	---
PF × FR	-0.021	0.051	0.237	0.03	-0.045	0.104	0.043
SS × FR	0.014	0.007	0.032	0.002	-0.009	0.016	0.003
PF × SS × FR	---	---	-0.001	---	---	---	---
F-ratio for total regression	2.415***	0.608	1.359	3.785	0.582	0.454	2.422**

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$
PF = peanut flour (%)
SS = screw speed (rpm)
FR = feed rate (kg/hr)

peanutty and bitter at $p \leq 0.1$. Among the seven attributes of aromatics and taste, multi-grainy, oil flavor, burnt, sweet, and salty had no effect at 10% level of significance.

Texture: Table 4.9 shows the analysis of variance (ANOVA) of descriptive attributes for texture, which are oiliness, roughness, hardness, crispness, crunchiness, fractrurability, persistence of crunchiness, persistence of fracturability, oily mouthfeel, and tooth pack. The attributes of roughness, hardness, crispness, crunchiness, fracturability, persistence of crunchiness, and persistence of fracturability were found to be singinficant at 1% level of significance. The linear effect of peanut flour was found to be significant on hardness, crispness, and crunchiness at $p \leq 0.01$, and on persistence of crunchiness at $p \leq 0.05$. The screw speed had a significant linear effect on rougnness at $p \leq 0.05$, and on hardness, and fracturability at $p \leq 0.01$. Feed rate had a linear effect on persistence of crunchiness at 5% level of significance. The quadratic effect of peanut flour was found to be significant on the attributes of hardness, crispness, crunchiness, persistence of crunchiness, and persistence of fracturability at $p \leq 0.01$, and on fracturability at $p \leq 0.1$. The quadratic effect of screw speed had a significant effect on hardness and crispness at $p \leq 0.01$, and $p \leq 0.1$, respectively. And also no quadratice effects of feed rate were found. Interaction effects between peanut flour and screw speed were found to be significant on the attributes of roughness, hardness, and persistence of crunchiness, at $p \leq 0.05$. Screw speed and feed rate had a significant interaction effect on roughness and persistence of fracturability at $p \leq 0.05$, and on hardness, fracturability, and persistence of crunchiness at $p \leq 0.01$. In addition, the interaction among peanut flour, screw speed, and feed rate found to be significant on the attributes of roughness,

Table 4.9. Analysis of variance for the overall effects of the variables for the texture in sensory descriptive attributes

variables	regression coefficients									
	oiliness	roughness	hardness	crispness	crunchiness	fracturability	persistence of crunchiness	persistence of fracturability	oily-mouthfeel	tooth pack
intercepts	30.133	130.573	8.843	163.329	-1.103	44.919	47.463	46.867	98.897	53.312
PF	0.002	-0.076	5.069***	-3.68***	3.219***	1.37	2.452**	2.119	-1.852	0.335
SS	-0.072	-0.214**	-0.475***	0.183	-0.202	-0.301***	-0.37	-0.217	-0.303	0.093
FR	3.585	-12.182	-1.865	-11.339	5.771	-1.162	-3.239*	-10.951	-6.528	3.97
PF × PF	0.002	-0.008	-0.071***	0.039***	-0.042***	-0.023*	-0.038***	-0.03***	0.004	0.004
SS × SS			0.003***	-0.002*						
FR × FR	-0.469	0.586	-0.557	0.943	-1.004	-0.905	-0.785	0.164	-0.727	0.119
PF × SS	-0.001	0.005**	0.007**	-0.001	0.004	0.004	0.006**	0.004	0.005	-0.002
PF × FR	-0.012	0.165	0.185	0.072	0.121	0.191	0.187	0.158	0.296	-0.122
SS × FR	0.003	0.038**	0.058***	-0.008	0.035	0.054***	0.063***	0.053**	0.042	-0.016
PF× SS× FR		-0.001**	-0.001**		-0.001	-0.001**	-0.001**	-0.001	-0.001	
F-ratio for total regression	0.439	3.97***	16.643***	7.88***	12.183***	6.169***	9.792***	5.766***	1.387	0.831

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$
PF = peanut flour (%)
SS = screw speed (rpm)
FR = feed rate (kg/hr)

hardness, fracturability, and persistence of crunchiness. Among the ten texture attributes, oilness, oily mouthfeel, and tooth pack had no effect at 10% level of significance.

Modeling the Descriptive Sensory Attributes of Peanut-Based Extruded Snack Products

Thirteen significant descriptive sensory attributes out of 22 attributes were obtained from regression analysis of the data at 10% level of significance. These were brown color, roughness, porosity, and puffiness for appearance, roasted peanutty and bitter for aromatics and taste, roughness, hardness, crispness, crunchiness, fracturability, persistence of crunchiness, and persistence of fracturability for texture. Significant regression model means that the variations in the sensory attributes can be effectively explained by the model. The other nine descriptive sensory attributes were found to be insignificant at 10% level of significance. Those attributes were dryness for appearance, multi-grainy, oil flavor, burnt, sweet, and salty, for aromatics and taste, and oiliness, oily mouthfeel, and tooth pack for texture. Subsequent data analyses were performed on the response variables of the remaining 13 attributes.

Stepwise regression analysis was applied to those significant variables obtained from the regression analysis (full model) resulted in the reduced models. The final reduced models for the descriptive sensory attributes of appearance, aromatics and taste, and texture presented are those that are not significantly different from full models at 10% level of significance. The predictive models for descriptive sensory attributes are presented in Table 4.10. These predictive models were used to plot contour maps to indicate the effects of formulation (peanut flour) and extrusion processing conditions (screw speed and feed rate) on the descriptive sensory attributes. And also, these models

Table 4.10. Predictive models for the significant sensory characteristics of peanut-based snacks from descriptive analysis

sensory attributes	predictive models	F-ratio	R^2
Appearance			
Brown color	$E(Y) = -24.6407+4.9628X_1+0.0105X_2-19.3647X_3-0.0439X_1^2+1.9717X_3^2 +0.0112X_2X_3-0.0003X_1X_2X_3$	54.264	0.97
Roughness	$E(Y) = 104.4881-1.9833X_1+0.0178X_2+2.0972X_3+0.0277X_1^2-0.0002X_1X_2X_3$	4.426	0.59
Porosity	$E(Y) = 68.6761-0.9728X_1+0.3279X_2+14.8156X_3+0.0296X_1^2-0.0073X_1X_2 -0.2846X_1X_3-0.0556X_2X_3+0.0011X_1X_2X_3$	7.870	0.83
Puffiness	$E(Y) = 180.4686-5.7133X_1+0.3626X_2+0.4124X_3+0.0638X_1^2-0.009X_1X_2 -0.0572X_2X_3+0.0013X_1X_2X_3$	26.983	0.85
Aromatics and Taste			
Roasted peanutty	$E(Y) = 25.6141-0.0957X_1+0.0033X_1^2$	8.982	0.50
Bitter	$E(Y) = 9.102-0.4065X_1-0.725X_3+0.004X_1^2+0.0249X_1X_3$	5.798	0.52
Texture			
Roughness	$E(Y) = 93.3905+0.0767X_1-0.116X_2+0.2686X_3+0.0023X_1X_2+0.0183X_2X_3 -0.0004X_1X_2X_3$	6.226	0.53
Hardness	$E(Y) = -18.2494+6.1158X_1-0.3546X_2-0.0497X_3-0.0725X_1^2+0.0003X_2^2 +0.004X_1X_2+0.0362X_2X_3-0.0007X_1X_2X_3$	20.668	0.53
Crispness	$E(Y) = 141.3173-3.7543X_1+0.1293X_2+0.9746X_3+0.0418X_1^2-0.0002X_2^2 -0.0064X_2X_3$	12.452	0.65
Crunchiness	$E(Y) = -7.7369+4.026X_1-0.1079X_2+0.5722X_3-0.0449X_1^2+0.0022X_1X_2 +0.0209X_2X_3-0.0005X_1X_2X_3$	17.269	0.69
Fracturability	$E(Y) = 48.1664+1.1328X_1-0.2371X_2-4.2891X_3-0.0202X_1^2-0.5924X_3^2 +0.0044X_1X_2+0.1914X_1X_3+0.0543X_2X_3-0.001X_1X_2X_3$	6.700	0.52

Table 4.10. Continued

sensory attributes	predictive models	F-ratio	R^2
Persistence of Crunchiness	$E(Y) = 12.7164+3.1973X_1-0.2076X_2+1.7567X_3-0.036X_1^2-0.5381X_3^2$ $+0.003X_1X_2+0.0407X_2X_3-0.0006X_1X_2X_3$	11.988	0.68
Persistence of Fracturability	$E(Y) = 8.3391+3.083X_1-0.087X_2-3.0079X_3-0.031X_1^2+0.0264X_2X_3$ $-0.0002X_1X_2X_3$	9.304	0.62

X_1=peanut flour (%)
X_2=screw speed (rpm)
X_3=feed rate (kg/hr)

can be used and serve as suitable approximating functions for the purpose of predicting future response and establishing the range of values needed for these descriptive sensory attributes of the peanut-based snack products.

Effects of Formulation and Extrusion Conditions on Sensory Attributes

Appearance: Fig 4.1 shows the contour plots of sensory attributes of brown color, roughness, porosity, and puffiness. The contours were plotted based on the predictive models with one factor kept constant and varying to the other two factors, which were found to be significant from the regression analysis at 10% level of significance. The contour for brown color was plotted at constant screw speed of 300rpm varying to the peanut flour and feed rate. The attribute of brown color was mainly affected by peanut flour: as the amount of peanut flour increased, brown color increased (Fig 4.1-a). Common browning of foods on heating or on storage is usually due to a chemical reaction between reducing sugars, mainly D-glucose, and a free amino group of amino acid that is part of a protein chain. This reaction is called the Maillard reaction. Under some conditions, brown color of products caused by Maillard reaction is desirable and important in some foods (Bemiller, J.N. and Whistler, R.L. 1996). The contour of roughness (Fig 4.1-b) was plotted at constant feed rate of 5kg/hr varying to peanut flour and screw speed. The roughness decreased with increasing peanut flour from 30 to 40%, and then increased from 40 to 50%, which means that there is a quadratic effect of peanut flour. Screw speed affected to the roughness inversely: roughness increased with decreasing screw speed. For the attributes of porosity and puffiness, the contours were plotted at constant feed rate of 5kg/hr varying in peanut flour and screw speed. The contours of porosity and puffiness were quite similar representing that the only difference was the intensity ratings of each attribute. So the effects of operating conditions for two attributes could be explained with one contour (Fig 4.1-c). For those porosity and puffiness, increasing peanut flour decreased the porosity and puffiness from peanut flour of 30 to 40% regardless of screw speed. However peanut flour from 40 to 50%, the amount of peanut flours and screw speed affected inversely to the porosity and puffiness: increasing peanut flour and screw speed decreased the porosity and puffiness. This result may be due to the chemical changes such as starch degradation during extrusion processing under high shear environment. A similar result was obtained from the previous study of physical properties. The volume expansion ratio (VER) decreased with increasing peanut flour, which means increasing peanut flour leads to a less puffed and hence a denser product. The VER also was affected by the starch gelatinization. As the screw speed and feed rate increased the degree of gelatinization decreased resulted in low expansion. It might be explained that increasing screw speed increases shear rate but also lowers the residence time, which reduces swelling making the granules less susceptible to shear action resulting in less starch gelatinization (Bhattacharya and Hanna, 1987). This lower gelatinization caused in the less expanded products.

Aromatics and Taste: The contour plots of the attributes of roasted peanutty and bitter are shown in Fig 4.2. The contours were plotted at constant screw speed of 300rpm varying to peanut flour and feed rate. Increasing peanut flour and feed rate increased roasted peanutty and bitter.

Texture: Fig 4.3 shows the contour plots of roughness (a), hardness (b), crispness (c), crunchiness and persistence of crunchiness (d), and fracturability and persistence of fracturability (e). The roughness decreased, as peanut flour decreased and screw speed

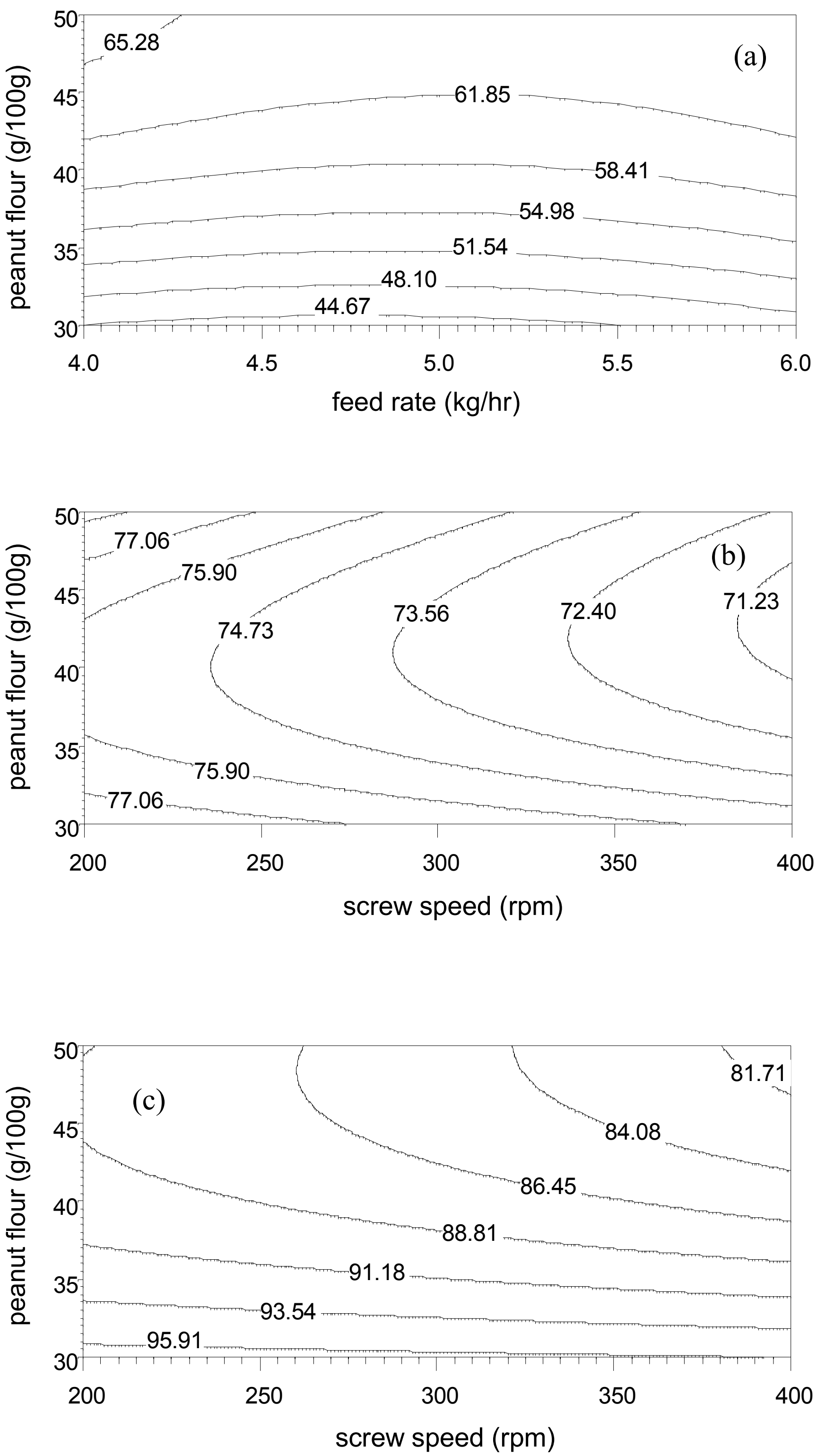
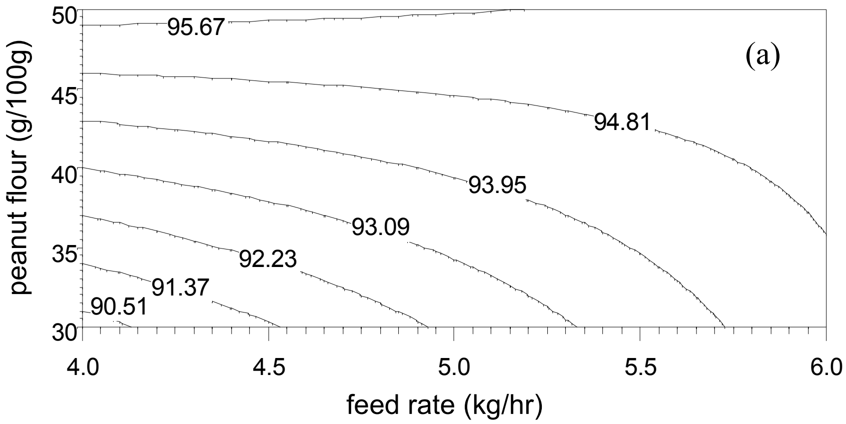


Fig 4.1. Contour plots of descriptive sensory attributes of (a) brown color, (b) roughness, and (c) porosity and puffiness



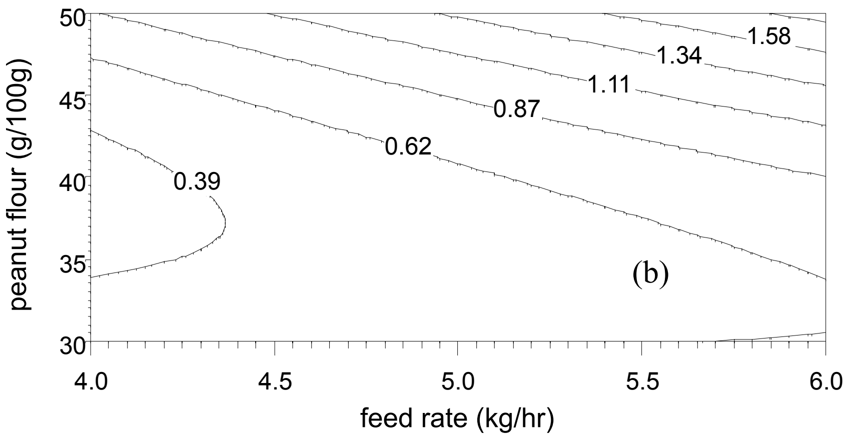


Fig 4.2. Contour plots of descriptive sensory attributes of (a) roasted peanutty and (b) bitter

increased (Fig 4.3-a). Contour plots indicates that the hardness and crispness are inversely related (Fig 4.3-b,c). The hardness increased as peanut flour increased from 30 to 40% regardless of screw speed, and from the peanut flour 40 to 50% there was no significant change on hardness due to peanut flour, but a change due to screw speed: hardness increased significantly at screw speed of 350-400rpm and peanut flour of 40 to 50%. For crispness, as the peanut flour increased from 30 to 40%, crispness decreased regardless of screw speed, and from 40 to 50% peanut flour, no significant changes were found due to the peanut flour. However, at the peanut flour range of 40-50%, increasing screw speed decreased crispness significantly. Generally crispiness decreased and hardness increased with increasing peanut flour. The contours of crunchiness and persistence of crunchiness was quite similar, so Fig 4.3-d could explain the both attributes. Crunchiness and persistence crunchiness increased with increasing peanut flour and feed rate. Fracturability and persistence of fracturability also increased with increasing peanut flour and feed rate (Fig 4.3-e).

Relationship between the Descriptive Analysis and Consumer Acceptance Test

Table 4.11 shows the correlations between the attributes of descriptive analysis and consumer acceptance test.

Appearance: brown color affected to the attribute of color and texture in consumer acceptance test, and roughness had a slight relationship with crispness. Porosity and puffiness affected to the overall liking, and porosity had a relationship with color and texture.

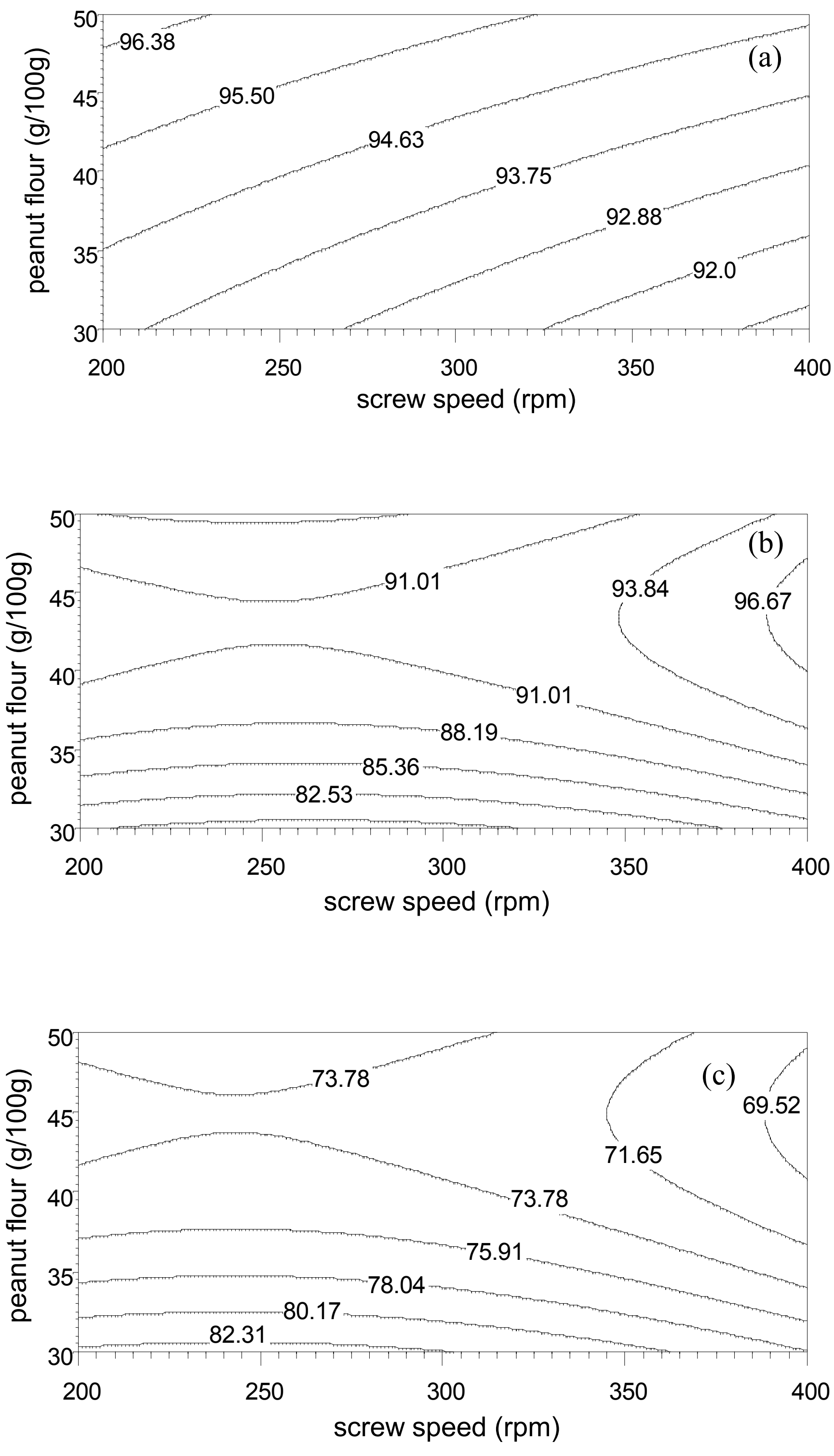


Fig 4.3. Contour plots of descriptive sensory attributes of (a) roughness, (b) hardness, and (c) crispness

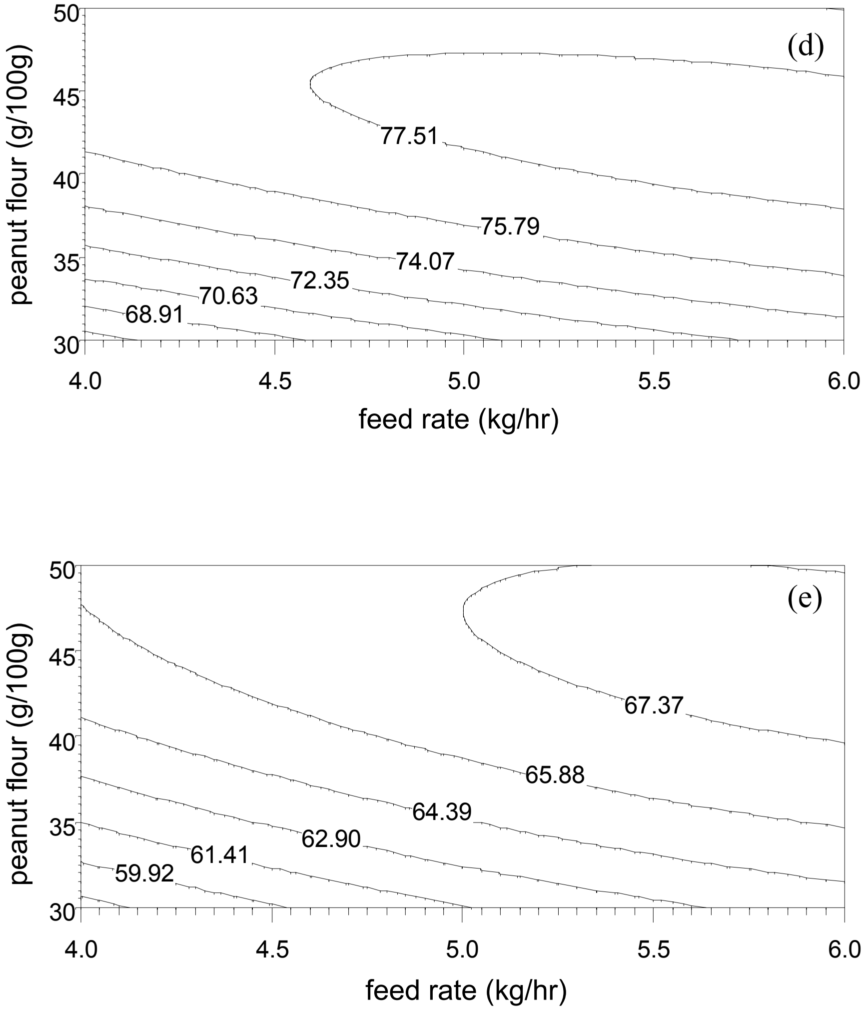


Fig 4.3. Contour plots of descriptive sensory attributes of (d) crunchiness and persistence of crunchiness and (e) fracturability and persistence of fracturability

Table 4.11. Significant correlations between the attributes of descriptive and consumer acceptance test

descriptive attributes	attributes in consumer test: overall liking	color	crispness	texture
Appearance				
brown color	ns	-0.528^{***}	ns	-0.357^{***}
roughness	ns	ns	0.129^{*}	ns
porosity	-0.224^{*}	0.433^{*}	ns	0.091^{*}
puffiness	0.445^{***}	ns	1.708^{***}	ns
Aromatics & Taste				
roasted peanutty	ns	ns	ns	ns
bitter	0.395^{**}	ns	ns	ns
Texture				
roughness	ns	-0.221^{*}	-0.346^{***}	0.169^{**}
hardness	0.148^{*}	ns	-0.107^{*}	ns
crispness	ns	ns	ns	ns
crunchiness	ns	ns	ns	ns
fracturability	ns	ns	-0.097^{**}	ns
persistence of crunchiness	ns	ns	0.155^{**}	ns
persistence of fracturability	ns	ns	ns	0.242^{***}

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Aromatics & Taste: bitterness only had a relationship with overall liking.

Texture: roughness was important to every attribute in consumer acceptance test except overall liking. Hardness had a relationship with overall liking and crispness. Whereas, crispness and crunchiness were found to be no significant relationship with attributes of consumer acceptance test. Fracturability had a relationship with crispness. Persistence of crunchiness and persistence of fracturability had a relationship with crispness and texture, respectively.

CONCLUSIONS

Quantitative Descriptive Analysis (QDA) was used to investigate the effects of formulations and extrusion processing conditions on peanut-based extruded snack products. The descriptive sensory evaluation indicated that the level of peanut flour was the most important variable in determining the overall sensory properties of snack products. High peanut flour snack products were characterized as to be darker brown color, lower puffiness and porosity, bitter flavor, and harder, whereas low peanut flour products were characterized as easier to be fractured and crisper.

ACKNOWLEDGEMENTS

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SECTION V

PHYSICAL PROPERTIES OF PEANUT-BASED EXTRUDED SNACKS USING A TWIN-SCREW EXTRUSION PROCESSING

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ABSTRACT

Blends of partially defatted peanut flour (12% fat) and rice flour at different ratio were extruded to produce indirectly, puffed snack products using a co-rotating, twin-screw extruder. The extrudates were dried to obtain half-products with 11-12% moisture content, and the half-products were expanded by deep-fat frying at 200ºC for 35-40 sec. The thickness and degree of gelatinization of half-products were measured, and the bulk density and volume expansion ratio of puffed snack products were measured. The physical properties of peanut-based extruded snack products were significantly affected by the amount of peanut flour in the formulation. A simultaneous decrease in peanut flour and feed rate resulted in increased degree of gelatinization and volume expansion ratio, but decreased bulk density. The optimum formulations and extrusion processing conditions were determined using Response Surface Methodology (RSM). The boundary for optimization was determined by consumer acceptance test. Individual contour plot of the degree of gelatinization, bulk density, and volume expansion ratio were superimposed, and the optimum regions were identified. The optimum regions were the square area of feed rate of 4.0-4.6kg/hr and peanut flour of 31.0-42.5%, and the area encompassing the linear line of feed rate of 4.6-6.0kg/hr and peanut flour from 42.5% to 37.0% to the intercept of the minimum contour line of the degree of gelatinization (71.17) and followed the line to peanut flour of 32.0%.

INTRODUCTION

According to a recent public survey, nearly three-quarters (73%) of 1,017 adults eat snacks at least once a day, one quarter (23%) eat snacks a few times a week, and only 4% never snack at all (Jones, 2000). A 1998 Gallup study of American Snacking Behaviors found that the most common motivations for snacking were to satisfy hunger between meals and to satisfy one's sweet tooth. More than 30% of the calories Americans consume today are in the form of snacks (Wikes, 2000).

Savory snacks are mainly classified into three generations based on the chronology of their introduction. The first-generation snacks refer to conventional potato chips and baked crackers. Second-generation snacks referred to as collets, are direct-expanded products, which are extruded with a low moisture extrusion (< 15%). Once extruded, the collets are dried to less than 4% and can be coated with flavors and oil. Third-generation snacks, referred to as semi-, half-, or intermediate- are pellets, which are cooked and formed by extrusion processing. The pellets are dried and are ready to be consumed after frying in hot oil or puffing in a hot air stream, which contribute to the final texture (Harper, 1981; Sunderland, 1996).

Extrusion technology has become one of the major processes for producing including, ready-to-eat foods such as breakfast cereals and snack foods as well as textrurized vegetable proteins, pre-gelatinized flour, and other food ingredients (Cheftel, 1986; Russell, 1988). Extrusion cooking is a high-temperature, short-time process that combines the operations of feed transport, mixing, working, and forming in an efficient way to transform raw ingredients into intermediate and finished products (Harper, 1989). Extruders provide thermal and shear energy to the food material, which then undergoes significant physical and chemical change. Meuser and Lengerich (1992) observed that the thermal energy generated by viscous dissipation during extrusion with combining shearing effect, quickly cooks the raw mixture so that the properties of materials are modified due to physico-chemical changes of the biopolymers, such as starch gelatinization, and protein denaturation.

The introduction of third-generation snacks has opened new avenues for snack food product introductions, and third-generation snacks are one of the fastest growing items in the snack food industry (Sunderland, 1996). In the manufacture of these snacks, semi-processed extrudates are prepared in different shapes or sizes by extrusion processing (McWard, 1994). In addition, dried half-products have the advantages of easy, prolonged storage and higher density transportation density compared to the directly expanded snacks, and the desired quantities of snacks can be produced whenever required (Van Laarhoven et al., 1991). A wide variety of cereal grain ingredients, including mixtures of grains, flour, and starch, can be used to produce these extruded snacks (Toft, 1979).

Peanuts are among the worlds' leading oilseeds, ranking fourth in world production behind soybeans, cottonseed, and rapeseed (Anon, 1998). In many countries, peanuts are considered as an oilseed crop grown primarily for oil production. The oil from peanut seed is of high quality, and a large portion of the world production of peanut is utilized as an edible oil source. After oil extraction, a protein-rich peanut flour, such as partially defatted peanut flour (PDPF) or defatted peanut flour (DPF), can be used for various food products. Peanut is a good source of supplementary protein and is used to produce widely accepted food products (Matz, 1993), and peanut flour may be added as an ingredient in extrusion products. Prinyawiwatkul et al.(1995) reported that partially defatted peanut flour has a relatively high protein content, bland flavor, and light tan color which facilitates its incorporation into a wide range of food products. They extruded cornstarch-peanut flour mixtures, and found that non-fermented or fermented partially defatted peanut flour can be incorporated into a potential snack product. Suknark et al.(1999) developed two high protein snack products from tapioca starch and fish muscle, and from tapioca starch and partially defatted peanut flour (PDPF) using twin-screw extrusion process followed by deep-fat frying.

In the United States, about more than 90% of the production goes into domestic food use, the end products being peanut butter (51.5%), salted roasted peanuts (24.6%), confectionaries (21.2%), and others (2%) (USDA 1992). Data from the National Agricultural Statistics Service (USDA, 2000) also indicated that the per capita consumption of peanuts in the U.S. is approximately 5.7 pounds a year, and more than half of this is consumed as peanut butter. Eissenstat et al. (1999) studied the impact of consuming peanuts and peanut products on the energy and nutrient intakes from 1994 to 1996, and reported that peanut users tended to achieve higher RDAs for micronutrients and had a higher fiber intake than nonusers. The percent energy from monounsaturated fatty acids (MUFA) was slightly higher in peanut users than non-users, but the percent of energy from saturated fat was comparable for user and nonusers. Energy intake was higher in peanut users, however overall diet quality was greater.

Starch and starch derivatives have been used in snack foods, especially as functional ingredients to help snacks achieve various textural attributes (Huang, 1995). The most common sources of starch used for snack products are cereals, such as corn, wheat, rice, and oats (Moore, 1994). Sheng (1995) reported that rice flour and starches could alter texture and improve expansion in breakfast cereals and snack foods. Moreover, due to the bland taste of rice flour, rice flour in blends does not mask the flavors of the other ingredients in finished products.

Snack foods, which normally contain mainly carbohydrate and fat, can be increased in protein content and nutritional value by adding protein sources, which consist of high-quality protein and also contain vitamins and minerals. These might include peanut, soybean, cowpea, fish, pork, beef, and chicken (Suknark et al., 1999). Ayes and Davenport (1977) observed that the addition of defatted peanut flour to corn curl formulations containing degerminated cornmeal and rice flour increased the protein content without adversely affecting bulk density or flavor; these snacks were processed by extrusion with partial steam cooking, drying, and deep-fat frying. Camire and King (1991) examined the effects of supplementation of protein and fiber for extruded cornmeal snacks, and found that soy protein isolate increased expansion and reduced collet bulk density.

Snack type food processing by extrusion cooking has been done by some researchers. Van Laarhoven and Staal (1991) produced third-generation snacks using an extruder composed a gelatinizing extruder and forming extruder, and examined the viscosity of the paste and the final snack quality by relating the back extrusion force-value required to press the paste with sensory properties of the snacks. Thakur and Saxena (2000) used Response Surface Methodology (RSM) to analyze the effects of ingredients on the sensory and objective (expansion ratios) attributes of an extruded snack food. They found that responses were most affected by changes in ingredients, which was the gum based cereal-pulse blend, and reported that the system of sensory score and expansion ratios of extruded snack food can be effectively optimized by RSM.

Response surface methodology (RSM) is reported to be an effective tool for optimizing a process when the independent variables have a joint effect on the desired response (Hunter, 1959). The effectiveness of response surface methodology (RSM) in the development and optimization of products and processes has been demonstrated by many researchers. The basic principle of RSM is to develop regression equations that describe inter-relations between input parameters and product properties (Colonna et al., 1984). Three-dimensional plots provide a useful visual aid for checking the adequacy and fit of the model and examing the behavior of the response surface and location of the optimum (Saxena and Rao, 1996). There has been little research on physical properties of half-products produced from partially defatted peanut flour and rice flour with high moisture content using a twin-screw extrusion process. The present research was conducted to develop new snack products produced from partially defatted peanut flour and rice flour using a twin-screw extrusion followed by deep-fat frying, to characterize the physicochemical properties of snack products, and to optimize the formulation and extrusion variables for peanut-based extruded snack products.

MATERIALS & METHODS

Materials

A mixture of peanut and rice flour was blended at three levels of peanut flour (30, 40, and 50%) to rice flour using a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY), and was extruded at three levels of feed rate (4, 5, and 6kg/hr) and screw speed (200, 300, and 400rpm) in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England). The temperature profiles of the extruder barrels was set to be 100, 120, 110, 95, and 80ºC from feed zone to die. The barrel temperatures of zone four and five was set blow 100ºC to prevent puffing of extrudates. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. Half-products were puffed by deep-fat frying at 200 ± 5ºC for 35-40sec in pure vegetable oil (The detailed procedure to produce half-products and final snack products is in Section II).

Proximate composition

Nitrogen content of half-products was determined using the LECO® Nitrogen Analyzer (Model FP-2000, LECO Cor., St, Joseph, MI) according to method 46-30 (Dumas conversion method, AACC 1983). Conversion factors for peanut flour (5.46) and rice flour (5.95) were used to convert nitrogen values obtained for the samples to crude protein. Fat content of the half-product and puffed fried snacks was determined by petroleum ether extraction (18hrs) using the Goldfisch extractor (Model 35001, Laboratory Construction Co., Kansas City, MO).

Degree of gelatinization

The degree of gelatinization was determined using the method described by Birch and Priestley (1973). This method is based on the formation of a blue iodine complex with amylose released from the granule as a result of the extrusion process or other hydrothermal process. The dry half-product samples were ground using Braun® coffee grinder (Model KSM2) roughly, and then through a 0.08mm screen in a microjet mill (Model ZM1, Retsch Co., West-Germany). Ground samples were dried in a forced air oven at 50ºC for 12hr and stored in air-tight containers over anhydrous $CaSO_4$ in a desiccator prior to oil extraction from the half-products. Oil was removed by petroleum ether extraction using the Goldfish apparatus (Model 35001, Laboratory Construction Co., Kansas City, MO). The oil-free, ground samples (0.2g) were dispersed in 98ml double deionized water, treated with 2ml of 10M KOH solutions, and then gently stirred for 5min. The suspension was centrifuged at 8,000rpm and 15ºC for 10min. A 1ml supernatant was removed, treated with 0.4ml of 0.5M HCl, and made up volume to 10ml with double deionized water. 0.1ml of I_2-KI solution (1g iodine and 4g potassium iodine in 100ml solution) was then added and stored in ambient temperature for 15min. Absorbance was read at 600nm with a diode array spectrophotometer (Model 8451A, Hewlett Packard, Avondale, PA) against a reference solution (absorbance A_1). The reference solution (1) contains all reagents except sample. The determination was repeated to obtain absorbance A_2. 1.0ml of 0.5M HCl was added to 1ml of supernatant, and made up volume to 10ml with double deionized water. After adding 0.1 ml of I_2-KI solution, the absorbance was read at 600nm against the reference solution (absorbance A_2). The reference solution (2) was made with all reagents except sample as described above. Percent degree of gelatinization of the sample was calculated by the ratio of the two absorbances ($A_1/A_2 \times 100$). Three measurements were performed on each treatment.

Thickness of Half-products

The thickness of half-products was measured using a Starrett Dial Indicator (model 200-010, Kitts Industrial Tools, Detroit, MI). The shape of half-products was a flatted square of 2.0 × 2.0 (cm). One piece of half-product was placed between upper and lower part of the device, and the thickness was measured by reading the indicator. Eight measurements were performed for each treatment.

Bulk Density

Bulk density of the expanded snacks was determined by volumetric displacement using glass beads (diameter of 40-50mesh, Delong Equipment Co., Atlanta, GA). Weight and volume of 2 pieces of each sample were measured for each treatment. The procedure was conducted by filling enough glass beads to cover the bottom of a 60ml plastic container whose top is flat, placing 2 pieces of snack sample in the container, and then adding glass beads until the container was approximately three-fourths full. The container was tapped on a wooden table 15 times and then tapped 10 times more while simultaneously adding glass beads to fill and overflow the beaker. The excess glass beads on the top of the container were removed by using a flat edge of a stainless steel scraper. The container with glass beads and 2 pieces of snack samples was weighed. The container with glass beads only also was weighed. The volume of sample was calculated as the difference between the volume of glass beads filled fully in the container with samples and the volume of glass beads filled without samples in the container. Bulk density (g/cm^3) was calculated by dividing each sample weight by its volume. Three measurements were performed on each treatment.

Volume expansion ratio (VER)

VER measurement procedure was conducted using glass beads (diameter of 40-50 mesh, Delong Equipment Co., Atlanta, GA) as bulk density was measured. The volume expansion ratio of the expanded product was calculated as the volume of expanded product divided by the volume of half-product. The sample size and weight were carefully considered upon choosing the samples, so the half-products would be comparable before and after expansion. Three measurements were performed on each treatment. The sample size and weight were carefully considered upon choosing the samples, so the half-products would be comparable before and after expansion.

Statistical analysis

Experimental data were analyzed using Statistical Analysis System (SAS Institute, Inc., 1990). Duncan's multiple comparison test was performed to determine which sample means were significantly different at $\alpha = 0.05$. Regression analysis (PROC REG) was used to determine the behavior of the response variables in relation to the set of independent factors. The significant terms of formulations and extrusion conditions were selected from the whole models at 10% level of significance resulting in the reduced model. Regression analysis (PROC REG) was applied with the reduced model to fit second order polynomial models. These models included all linear and quadratic terms of the individual independent factors and all interaction terms (cross-products) of the linear terms. Linear terms were always retained in the model when a quadratic or a cross-product term involving that linear term was included. Response Surface Methodology (RSM) was applied to determine the effects of the significant factors on the response surface. Predictive models were used to plot the response surface and contour maps, which were used to optimize the formulations and extrusion processing conditions. The response surfaces and contours for these models were plotted as a function of two variables, which was the most significant, while keeping other variable at a fixed level. Optimum area was identified by superimposing the individual contour plots.

RESULTS & DISCUSSION

Extrusion Effects on the Physical Properties of Half-Products

The recorded values of process variables during extrusion and the compositions for the three mixtures are shown in Table 5.1. The values of variables for every run were recorded once reaching constant values. The temperature in the last zone and at die was required to be <100ºC in order to produce flat, thin, bubble-free extrudates. The last zone (zone 4) and die were set 95ºC and 80ºC, respectively, and this barrel temperature profile resulted in a product temperature at the die of 78-82ºC. For all extrusion conditions, die pressures ranged from 80 to 180 (psi), and torque ranged from 11 to 17%, which is relatively low, due to the high moisture content (40%) of the dough. High moisture content usually produces less viscosity than low feed moisture content resulting in low torque.

The protein content of half-products ranged from 18 to 26%. Products with higher levels of peanut flour contained more protein than products extruded with lower levels of peanut flour. Fat content of half-products varied from 0.7 to 4.4% depending on the level of peanut flour.

Physical Properties of Half-Products

Degree of Gelatinization: Granule swelling is a important factor in starch gelatinization, and depends on the strength and character of the micellar network within the granule. During extrusion cooking, heating disrupts internal hydrogen bonding which hold starch granules together, leading to the swelling of the granules and subsequent release of starch molecules, mostly amylose. The swelled granules are increasingly

Table 5.1. Recorded values of process variables during extrusion, and protein and fat content of half-products

Extrusion runs			dough temp. (ºC)		die pressure (psi)	torque (%)	protein (%)	fat (%)
PF	SS	FR	T_{C1}	T_{C3}				
30	200	4	98	81	90	12	18.45	0.91
30	200	5	99	80	140	14	18.43	1.09
30	200	6	100	80	120	11	18.34	0.96
30	300	4	100	81	100	15	18.40	0.91
30	300	5	99	80	130	15	18.43	0.90
30	300	6	100	80	150	15	18.45	0.70
30	400	4	102	81	80	17	18.60	0.82
30	400	5	99	82	90	14	18.49	0.84
30	400	6	98	81	90	12	18.40	0.69
40	200	4	100	81	140	13	21.92	1.81
40	200	5	99	80	170	14	21.94	1.75
40	200	6	103	80	180	13	21.77	1.71
40	300	4	99	80	130	15	21.94	1.34
40	300	5	100	80	160	15	21.97	1.56
40	300	6	101	80	180	15	21.84	1.40
40	400	4	100	81	80	16	22.04	1.68
40	400	5	100	81	130	16	21.96	1.73
40	400	6	100	80	160	16	21.85	1.64
50	200	4	103	81	110	13	24.40	2.40
50	200	5	102	78	130	11	25.11	2.09
50	200	6	101	78	150	13	26.15	3.72
50	300	4	101	81	110	14	25.38	2.69
50	300	5	101	78	140	14	25.35	2.34
50	300	6	101	78	160	14	25.36	2.77
50	400	4	101	80	70	13	26.09	4.37
50	400	5	102	82	120	13	26.02	4.24
50	400	6	101	81	150	13	25.23	2.47

PF = peanut flour (%), FR = feed rate (kg/hr), SS = screw speed (rpm) susceptible to disintegration by shear that exists in an extruder barrel (Ibanoglu et al. 1996; Bhattacharya and Hanna, 1987a).

Table 5.2 shows the mean scores of gelatinization of half-products extruded with three different ratios of peanut flour at three levels of screw speeds and feed rates. Increasing the level of peanut flour slightly decreased the degree of gelatinization varying with the screw speed and feed rate. As the feed rate increased the degree of gelatinization decreased significantly for the snack products extruded with peanut flour of 30% and 40%. It may be explained that at low barrel temperature, the starch gelatinization as feed rate increased, may not be high enough to cause much starch gelatinization. It was observed that an increase in feed rate reduces the mean residence time at a given screw speed, which could reduce the gelatinization due to a shorter processing time (Anderson et al. 1969; Ibanoglu et al. 1996). Whereas for the 50% peanut flour snack product, there was a little difference along with increasing feed rate.

The degree of gelatinization varied relatively little with screw speed. The lowest peanut flour (30%) snack product extruded at screw speed of 300rpm and feed rate of 5kg/hr showed the highest degree of gelatinization, which was 94.92%. For 40% and 50% peanut flour snacks, the highest value was at screw speed of 400rpm and feed rate of 4kg/hr (91.44%), and at screw speed of 400rpm and feed rate of 5kg/hr (92.56%), respectively. The gelatinization was high at 300rpm screw speed for 30% peanut flour, but at 400rpm for 40 and 50% peanut flour. It could be explained that the ingredients reacted differently varying to the ratios of blending ingredients. For the snack product extruded with 30% peanut flour, the degree of gelatinization decreased at the highest screw speed of 400rpm. It might be explained that increasing screw speed increases shear

Table 5.2. Means for degree of gelatinization of half-products at different screw speeds and feed rates

Feed rate (kg/hr)	PF:RF (30:70)				PF:RF (40:60)				PF:RF (50:50)			
	200	300	400	means	200	300	400	means	200	300	400	means
4	90.35a	90.70b	93.28a	91.44a	90.67a	86.26a	91.44a	89.46a	91.97a	87.78b	89.03b	90.26a
5	90.03b	94.92a	92.63b	92.53a	85.75b	83.59b	85.38b	84.91a	86.35b	87.01c	92.56a	88.64a
6	67.74c	75.47c	65.68c	69.63b	58.13c	63.60c	81.06c	67.60b	82.84c	94.74a	88.29c	88.62a
means	82.70b	87.03a	83.86b		78.18b	77.82b	85.96a		87.72a	89.84a	89.96a	

a-c means with different letters in the same column at each screw speed are significantly different at $p \leq 0.05$.
PF = peanut flour (%)
RF = rice flour (%)

but also lowers the residence time, which reduces swelling making the granules of high starch mixture less susceptible to shearing action. However, the degree of gelatinization increased with an increase of screw speed for the snack products containing 40% and 50% peanut flour, which had less starch granules compare to the 30% peanut flour products. It may indicate that as the residence time is reduced, the internal hydrogen bonding which hold starch granules together would not be disrupted so that less amylose would be solubilized resulting in reduced degree of gelatinization (Blanshard, 1979).

Thickness of half-products: Thickness of half-product is one of the important factors affecting the physical properties of the half-product after deep-fat frying. Table 5.3 shows the mean scores of thickness of half-products at different screw speed and feed rate of three different levels of peanut flour mixtures.

The thickness of half-products slightly varied with the level of peanut flour. The lower level of peanut flour, the thicker half-products was produced. This may be due to the high content of rice flour in the formulation. Increased feed rate at a constant screw speed resulted in an increase in thickness of half-products. The thickness of 30% peanut flour half-product ranged from 1.14 to 1.37, whereas for 40% and 50% peanut flour products ranged from 0.98 to 1.28 and from 1.04 to 1.24, respectively. For all three types of snack products, the highest mean score of thickness was given to the products extruded at screw speed of 300rpm. The thickest value of 1.376 was given to the half-product extruded with peanut flour of 30% at feed rate of 6kg/hr and screw speed of 300rpm. Whereas, the thinner half-product, which was the thickness value of 0.981 was given to the product extruded with 40% peanut flour at the highest screw speed of 400rpm and lowest feed rate of 4kg/hr. This might be due to the low amount of raw materials per

Table 5.3. Means of thickness of half-products at different screw speeds and feed rates

Feed rate (kg/hr)	PF:RF (30:70)				PF:RF (40:60)				PF:RF (50:50)			
	200	300	400	means	200	300	400	means	200	300	400	means
4	1.219c	1.329a	1.145c	1.231b	1.159b	1.201b	0.981c	1.114c	1.133b	1.156b	1.084b	1.124b
5	1.272b	1.262b	1.214b	1.249b	1.177b	1.204b	1.161b	1.181b	1.126b	1.187ab	1.041b	1.118b
6	1.314a	1.376a	1.342a	1.344a	1.242a	1.282a	1.232a	1.252a	1.195a	1.242a	1.174a	1.203a
means	1.268b	1.322a	1.233b		1.193a	1.229a	1.125b		1.151b	1.195a	1.099c	

a-c means with different letters in the same column at each screw speed are significantly different at $p \leq 0.05$.
PF = peanut flour (%)
RF = rice flour (%)

time unit conveyed in the barrel during high screw speed resulting in the occurrence of thin extrudate (Suknark et al., 1999).

Physical Properties of Puffed Snack Products

Bulk Density: Table 5.4 shows that the mean scores of bulk density of puffed snack products at different screw speed and feed rates. Increasing the level of peanut flour significantly increased the bulk density of puffed snack products, which indicated that increasing peanut flour resulted in a more dense products. In addition, as the feed rate increased the bulk density increased. For the snack product containing 30% peanut flour, the bulk density ranged from 0.204 to 0.277, and for those containing 40% and 50% peanut flour, the range of bulk density was from 0.258 to 0.355, and from 0.333 to 0.382, respectively. The lowest bulk density value of 0.204 and 0.205 was observed in the snack product with the lowest level of peanut flour (30%) extruded at feed rate of 4 and 5 kg/hr and the screw speed of 400 rpm. The bulk density of puffed snack products varied very slightly with the screw speed: generally, increasing screw speed resulted in a decrease of bulk density.

Volume Expansion Ratio (VER): The mean scores of the volume expansion ratio at different screw speeds and feed rates were presented in Table 5.5. A significant difference was found in the snack products containing 30% peanut flour depending on the feed rate and screw speed, whereas there was a relative less mean difference for the 40% and 50% peanut flour snack products. VER for 30% peanut flour snack product ranged from 5.85 to 10.78, for 40% peanut flour snack product from 4.24 to 6.21, and for 50% peanut flour snack product from 2.63 to 5.14. Increasing the level of peanut flour

Table 5.4. Means for bulk density of puffed snack products at different screw speeds and feed rates

Feed rate (kg/hr)	PF:RF (30:70)				PF:RF (40:60)				PF:RF (50:50)			
	200	300	400	means	200	300	400	means	200	300	400	means
4	0.209b	0.233a	0.205b	0.215b	0.299a	0.310a	0.258b	0.289b	0.333a	0.342b	0.346a	0.340b
5	0.237b	0.246a	0.204b	0.229b	0.302a	0.323a	0.301a	0.307b	0.355a	0.369a	0.353a	0.359a
6	0.277a	0.251a	0.266a	0.265a	0.355a	0.319a	0.330a	0.334a	0.352a	0.382a	0.376a	0.370a
means	0.241a	0.243a	0.225a		0.319a	0.317a	0.296a		0.347b	0.364a	0.358ab	

a-b means with different letters in the same column at each screw speed are significantly different at $p \leq 0.05$.
PF = peanut flour (%)
RF = rice flour (%)

Table 5.5. Means for volume expansion ratio of puffed snack products at different screw speeds and feed rates

Feed rate (kg/hr)	PF:RF (30:70)				PF:RF (40:60)				PF:RF (50:50)			
	200	300	400	means	200	300	400	means	200	300	400	means
4	10.783a	7.895a	9.654a	10.111a	4.909a	5.828a	5.994a	5.577a	5.139a	3.711b	4.903a	4.584a
5	9.022ab	6.919a	7.538b	7.826b	4.696a	6.213a	4.824a	5.244a	3.188b	3.561b	4.929a	3.893a
6	7.599b	6.944a	5.853b	6.799b	4.243a	4.349a	6.136a	4.904a	3.903ab	4.955a	2.632b	3.830a
means	9.801a	7.253b	7.682b		4.616a	5.463a	5.651a		4.077a	4.076a	4.155a	

a-b means with different letters in the same column at each screw speed are significantly different at $p \leq 0.05$.
PF = peanut flour (%)
RF = rice flour (%)

significantly decreased the volume expansion ratio of puffed snack products. The volume expansion ratio also varied with the level of screw speeds and feed rates. As the feed rate increased the volume expansion ratio decreased dramatically for the snack product containing 30% peanut flour, whereas relatively less for the snack products containing 40% and 50% peanut flour. The value of VER also varied with the level of screw speeds depending on the amount of peanut flour. The highest value of VER was given to the product containing 30% peanut flour extruded at lowest screw speed of 200rpm. However, the value of VER was the opposite for the product containing 40% and 50% peanut flour: the highest value of VER was given to those extruded at highest screw speed of 400rpm. In addition, the volume expansion ratio was changed dramatically for the snack product containing 30% peanut flour from 200rpm and to 300 and 400rpm compared to the snack products containing 40% and 50% peanut flour. The highest VER of 10.78 was given to the 30% snack product extruded at feed rate of 4kg/hr and screw speed of 200rpm, whereas the lowest VER of 2.63 was given to the 50% snack product extruded at feed rate of 6kg/hr and screw speed of 400rpm.

Effects of Variables on Physical Properties of Half-Products and Puffed Snack Products

ANOVA table of the physical properties of half-product and puffed snack products is shown in Table 5.6. The coefficient of determination (R^2) is the proportion of variability in the data explained or accounted for by the model, and large values of R^2 indicate a better fit of the model to data (Saxena and Rao, 1996).

Degree of Gelatinization: The linear terms of peanut flour, screw speed, and feed rate had a significant effect on the degree of gelatinization at 5%, 10%, and 1% level of

Table 5.6. ANOVA summary of variables in the model

Variables	regression coefficients: Degree of gelatinization	Thickness of half-products	Bulk density	Volume expansion ratio
Intercept	82.167	2.542	-0.384	82.792
PF	-4.448**	-0.039***	0.021***	-1.889***
SS	0.287*	0.001	0.001	-0.113*
FR	46.993***	-0.387***	0.029	-10.402**
PF × PF	0.062***	0.0003***	-0.0001***	0.009***
SS × SS	---	-0.000007***	-0.000001**	---
FR × FR	-5.856***	0.029***	0.003	0.314
PF × SS	-0.009*	---	---	0.002
PF × FR	-0.072	0.002	-0.001	0.155*
SS × FR	-0.054	0.001**	---	0.013
PF × SS × FR	0.002	---	---	---
R^2	0.770	0.863	0.933	0.777

*** significant at $p \leq 0.01$
** significant at $p \leq 0.05$
* significant at $p \leq 0.10$
PF means peanut flour (%)
SS means screw speed (rpm)
FR means feed rate (kg/hr)

significance, respectively. In addition, the quadratic effects of peanut flour and feed rate was found to be significant at 1% level of significance, and interaction of peanut flour with screw speed was also found to be significant at 10% level of significance. Regression analyses for the degree of gelatinization indicate that the fitted quadratic models accounted for 77.0% in the experimental data. Fig 5.1 shows the response surface of the degree of gelatinization as a function of peanut flour and feed rate. The surface plots indicated that the degree of gelatinization decreased from low (30%) to medium level of (40%) of peanut flour, and then increased from medium (40%) to high (50%) peanut flour showing the quadratic effects of independent factors were significant. As the screw speed and feed rate increased the degree of gelatinization decreased. It may be explained that increasing screw speed increases shear rate but also lowers the residence time, which reduces swelling making the higher starch granules less susceptible to shearing action (Bhattacharya and Hanna 1987b). Ibanoglu et al. (1996) investigated the effect of barrel temperature, feed rate, and screw speed on starch gelatinization during extrusion processing of tarhana, a traditional Turkish yogurt-wheat flour mixture. They found that the most significant factor on degree of gelatinization was barrel temperature followed by feed rate and screw speed. Chaing and Johnson (1977) studied the influence of extrusion variables on the gelatinization of wheat flour. Gelatinization of starch sharply increased at temperature above 80ºC. Higher moisture also gave a higher degree of gelatinization, though the effect was less pronounced than temperature. Whereas, increasing screw speeds gave lower levels of gelatinization.

Thickness of Half-Products: Regression analysis of thickness of half-products indicated that the linear effect of peanut flour and feed rate was found to be significant at

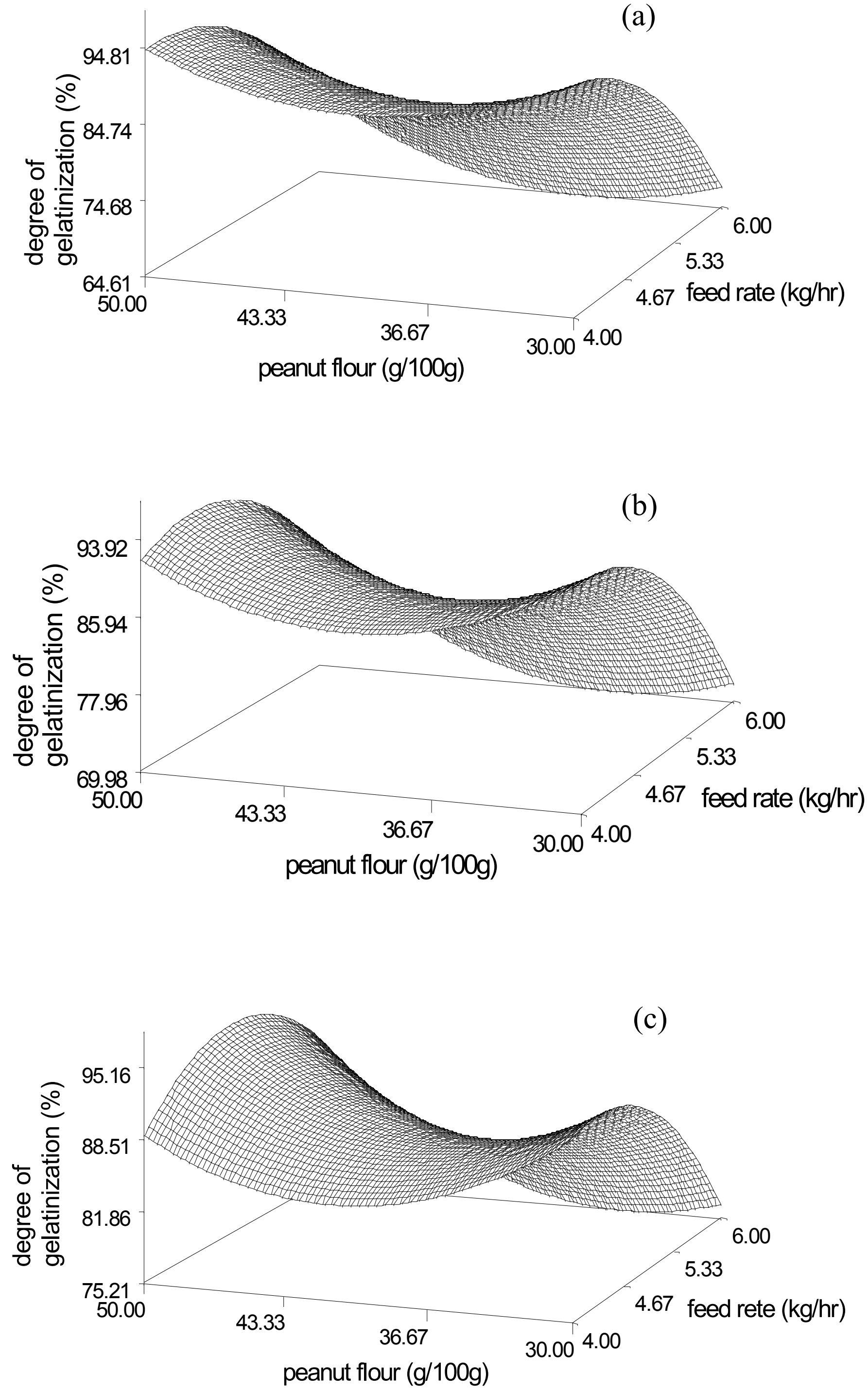

Fig 5.1. Response Surfaces of degree of gelatinization as a function of peanut flour (%) and feed rate (kg/hr) at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm

1% level of significance, but the linear term of screw speed had no effect on thickness of half-product at 10% level of significance. The quadratic terms of peanut flour, screw speed, and feed rate had significant effects on the thickness of half-products at 1% level of significance. The cross-product effects of screw speed and feed rate were also found to be significant at 5% level of significance in the model. The fitted quadratic model for the thickness of half-products accounts for 86.3% in the experimental data. Fig 5.2 shows the response surface of the thickness of half-product as a function of peanut flour and feed rate. The surfaces are similar to one another but not in magnitude. An increase in feed rate resulted in an increase in the thickness, whereas an increase in peanut flour resulted in a decrease in the thickness even this decrease is less dramatic compared to changes of feed rate. The shape of the response surface shows that the linear terms were the most significant.

Bulk Density: It was observed that the linear effect of peanut flour was significant at 1% level of significance. The effect of screw speed and feed rate was found to be insignificant at the probability of 10% level, which means bulk density was independent of screw speed and feed rate. The quadratic terms of peanut flour and screw speed had an effect on the bulk density at 1% and 5% level of significance, respectively. Whereas, no significant effects of cross-products among three independent variables were found in the model. The fitted quadratic model for bulk density accounts for 93.3% of the total variation in the experimental data, which is very significant. Fig 5.3 shows the response surfaces of bulk density of puffed snack products developed as a function of peanut flour and feed rate indicating that the linear terms of independent factors mainly affected to the bulk density. From the surface plots it can be explained that the screw speed and feed

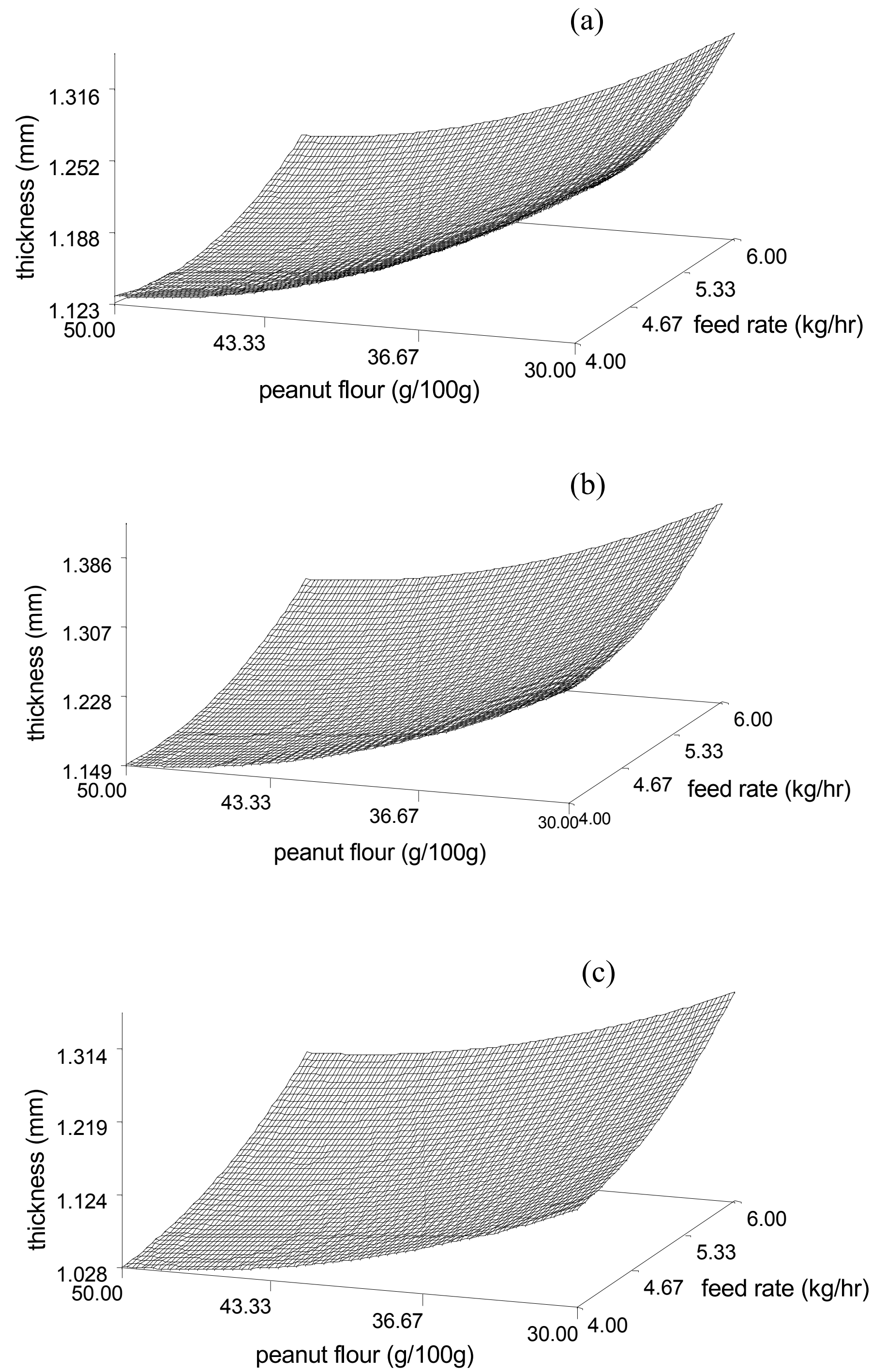

Fig 5.2. Response Surfaces of thickness of half-products as a function of peanut flour (%) and feed rate (kg/hr) at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm

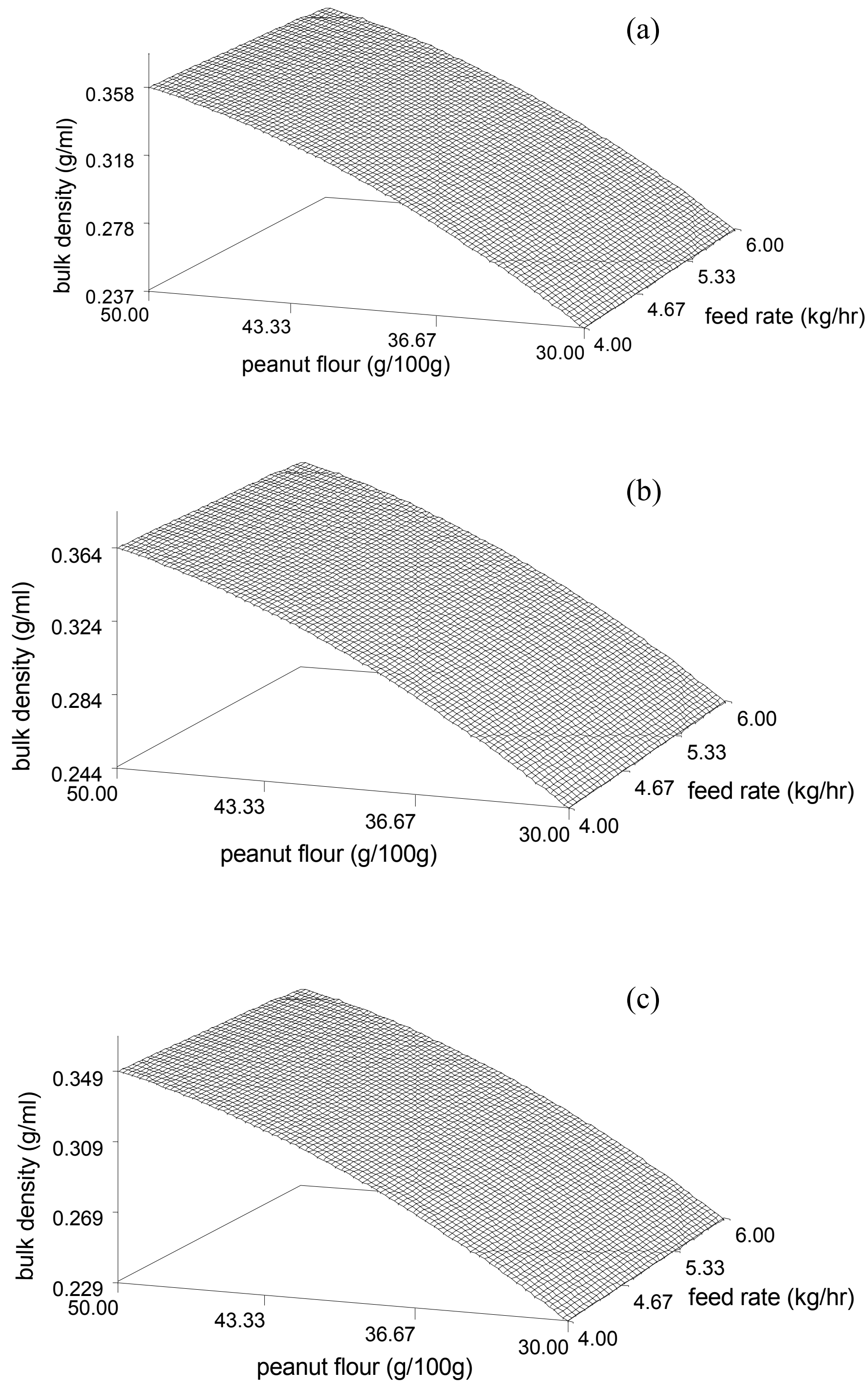

Fig 5.3. Response Surfaces of bulk density as a function of peanut flour (%) and feed rate (kg/hr) at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm

rate had no effect to the bulk density of puffed snack products as shown in the ANOVA table. However, an increase in peanut flour resulted in dramatically an increase in bulk density of puffed snack product.

Liu et al. (2000) reported a relatively similar result. They extruded the blends of corn flour and four different percentages of oat flour using a co-rotating twin-screw extruder, and found that increasing the percentage of oat flour resulted in extrudates with higher bulk density, but screw speed had no significant effects on the bulk density and volume expansion ratio. Ilo et al. (1996) examined the effects of feed rate, product temperature, feed moisture content, and die length in extrusion-cooked maize grits using counter-rotating twin-screw extruder. The results also showed that the feed moisture content and product temperature were found to be significant on the bulk density, but feed rate and die length had no significant effects.

Some researchers studied the effects of barrel temperature, dough moisture content, and screw speed on directly expanded extrudates during extrusion processing. Rayas-Duarte et al. (1998) found that dough moisture and process temperature appeared to be the most important factors for predicting bulk density. Bhattacharya and Hanna (1987b) reported that the bulk density of the extrudates increased with increasing moisture content, but decreased with increasing temperature.

Volume Expansion Ratio: The linear terms of three variables contributed to the model. It was observed that the linear effect of peanut flour was significant at 1% level of significance, and screw speed and feed rate also had a linear effect on volume expansion ratio at 10% and 5% level of significance, respectively. The quadratic terms of peanut flour had significant effect on the volume expansion ratio at 1% level of

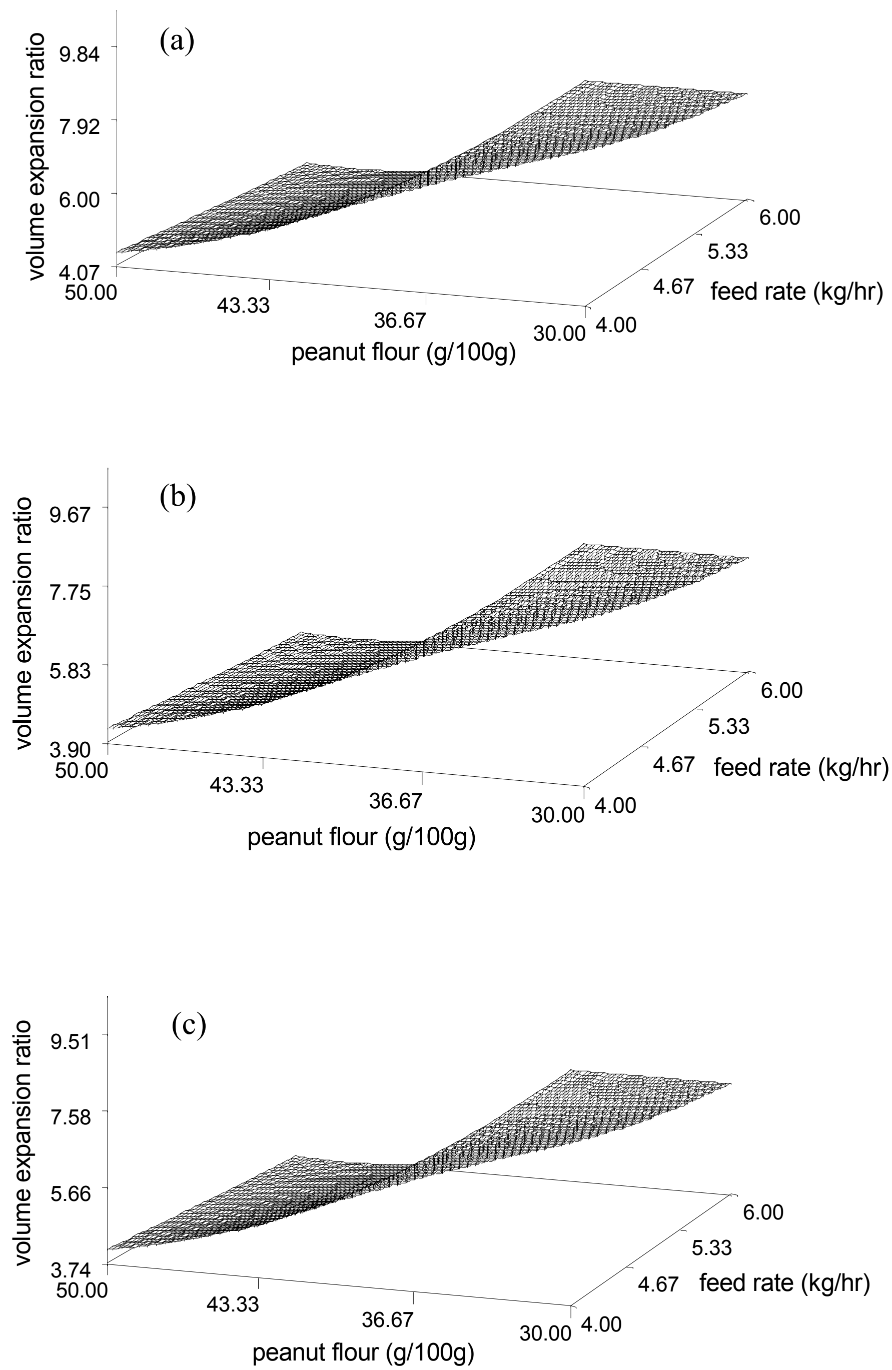

Fig 5.4. Response Surfaces of volume expansion ratio as a function of peanut flour (%) and feed rate (kg/hr) at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm

significance, and a cross-product effect between peanut flour and feed rate was found to be significant at 10% level of significance. The response surface of volume expansion ratio (VER) as a function of peanut flour and feed rate shows that the effects of peanut flour were more dramatic than that of feed rate indicating that the level of peanut flour is the most significant factor affecting volume expansion ratio during extrusion (Fig 5.4). Volume expansion ratio was decreased with increasing peanut flour and feed rate: increasing peanut flour leads to a less puffed and hence a denser product.

Effects of Physical Properties between Half-Products and Puffed Snack Products

The degree of gelatinization and thickness of half-products were examined to determine their effects on bulk density and volume expansion ratio of the final puffed snack products. The half-product extruded with the lowest peanut flour (30%) at the lowest feed rate (4kg/hr) showed the high degree of gelatinization resulting in the lower bulk density and higher volume expansion ratio of final expanded snack products. It was observed that the product volume expansion ratio was positively related with degree of gelatinization, but inversely with bulk density.

A similar observation was reported by Bhattacharya and Hanna (1987b) for corn grits extrudates. They reported that as temperature is increased gelatinization is more complete, resulting in more expansion and reduced bulk density. Case et al. (1992) extruded wheat/corn flour and starch to make half-product using twin-screw extruder. They reported that starch was gelatinized from 20 to 100%, and as gelatinization increased, the volume of the puffed product increased, whereas bulk density decreased. Suknark et al. (1999) reported that the degree of gelatinization and thickness of half-products affected the physical properties of puffed products after frying. As degree of gelatinization increased, the expansion of puffed product increased and bulk density decreased during subsequent frying. Thicker half-products provided lower expansion and higher bulk density of fried, expanded products.

However, the effect of half-product on the thickness in this study was the opposite of that observed in study of Suknark et al. (1999). The formulation of the lowest peanut flour (30%) extruded at the lowest feed rate (4kg/hr) produced thicker half-product, providing higher volume expansion ratio of puffed snack products. It may be explained that the higher amount of rice flour produced thicker half-products, but the high portion of rice flour functioned increasing expansion of final fried snack products.

Optimization

Predictive Regression Models: The regression models in Table 5.7 were used to generate the response surfaces of degree of gelatinization, thickness of half-products, bulk density, and volume expansion ratio. These models were also used to plot contour maps to optimize the formulations and extrusion conditions. The significant independent factors were selected at 10% level of significance from the whole models resulting in the reduced models. Each model included all linear and quadratic terms of the individual independent factor and all cross-products of linear terms. Linear terms were always retained in the model when a quadratic or a cross-product terms involving that linear term was included. The coefficient of determination (R^2) of the degree of gelatinization, the thickness of half-products, the bulk density and the volume expansion ratio of expanded snack products (R^2 = 0.74, R^2 = 0.86, R^2 = 0.83, and R^2 = 0.73, respectively) were relatively high for a response surfaces and contour plots. Among three independent factors, the effect of peanut flour and feed rate was found significant for all physical

Table 5.7. Predictive regression models for physical properties of peanut-based extruded snack products

Response variables	Predictive Models	R^2
Degree of gelatinization	$E(Y) = 123.339863 - 4.808407X_1 + 0.007797X_2 + 39.033926X_3 + 0.061990X_1^2 - 5.855574X_3^2 - 0.004717X_1X_2 + 0.000997X_1X_2X_3$	0.735
Thickness	$E(Y) = 2.19523 - 0.02992X_1 + 0.002719X_2 - 0.307069X_3 + 0.000295X_1^2 - 0.000007038X_2^2 + 0.028733X_3^2 + 0.000249X_2X_3$	0.855
Bulk density	$E(Y) = -0.235593 + 0.017556X_1 + 0.000592X_2 - 0.000144X_1^2 - 0.000001061X_2^2$	0.825
Volume expansion Ratio	$E(Y) = 45.652172 - 1.271157X_1 - 0.001677X_2 - 3.346836X_3 + 0.009304X_1^2 + 0.063946X_1X_3$	0.733

X_1 = peanut flour (%)
X_2 = screw speed (rpm)
X_3 = feed rate (kg/hr)

properties followed by screw speed. Therefore, the response surfaces and contour plots are based on the predictive models with a constant screw speed of 300rpm and varying to the peanut flour and feed rate within the experimental range.

Predictive models are useful in indicating the direction in which to change variables in order to maximize the physical properties of snack products, and provide the information about the influence of each variable on the each physical variable. These models are the optimized conditions that provide the information to produce a consistent quality product (Saxena and Rao, 1996).

Optimum Extrusion Conditions: The minimum and maximum value for reference to predict the optimum area of ingredients and extrusion conditions was determined by sensory test. Consumer acceptance test was conducted to determine the acceptability of peanut-based extruded snack products to consumers. The attributes of overall liking, color, flavor, crispness, and texture was rated in consumer acceptance test. The consumer rating of 6.0 or greater was considered to be acceptable to consumers using a 9-point hedonic scales (9.0 = like extremely, 6.0 = like slightly, 1.0 = dislike extremely, Peryam and Pilgrim, 1957), so that rating of 6.0 was used as the boundary value for optimization of the snack products. Contour plots for each sensory attribute were generated with their predictive models as a function of peanut flour and feed rate at a fixed screw speed of 300rpm. Optimum area was identified by superimposing the individual contour plots (Fig 5.5). The optimum ranges were bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR., and decreasing to 31.5% PF and 6.0kg/hr FR. Peanut-based extruded snack products produced within these ranges

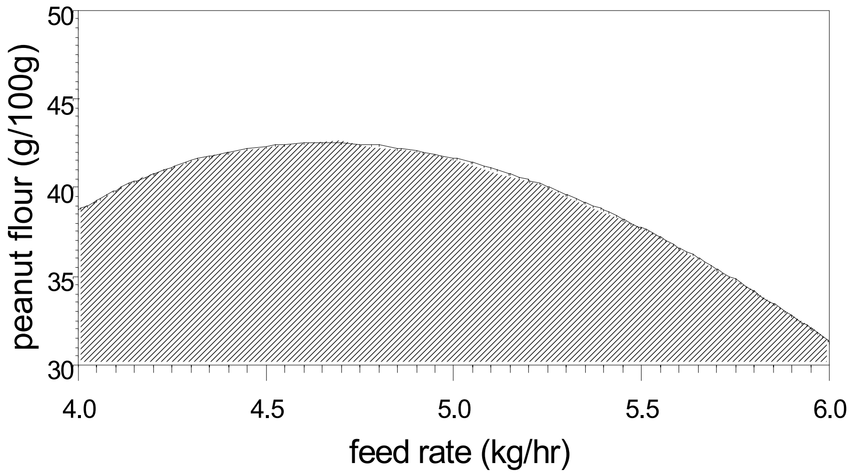

Fig 5.5. Superimposed contour plot for the consumer acceptance for the peanut-based snack products as a function of peanut flour(%) and feed rate(kg/hr). The optimum regions was bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39.0% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr FR.

will be rated 6.0 or greater for acceptance by consumer. In order to determine the critical value to predict the optimum ranges for physical properties, ten points of optimum conditions around the optimum curve (Fig 5.5) were selected. The mini- and maximum critical values of the degree of gelatinization, bulk density, and volume expansion ratio for optimization were calculated by substituting those ten point values of optimum conditions to the predictive models. The minimum critical values determined from predictive models were the degree of gelatinization of 71.08, bulk density of 0.25, and volume expansion ratio of 4.95. Whereas the maximum values were the degree of gelatinization of 93.10, bulk density of 0.33, and volume expansion ratio of 9.67. The minimum and maximum values were used as the boundary to optimize the formulations and extrusion conditions to produce peanut-based extruded snack products to be acceptable to consumers. The shaded area in the contour plots shown in Fig 5.6 was the optimum area of (a) the degree of gelatinization, (b) bulk density, and (c) volume expansion ratio. It was assumed that degree of gelatinization of 71.17 or above, bulk density between 0.25 and 0.33, and volume expansion ratio of 4.95 or above was acceptable to consumers. The optimization was performed by superimposing the individual contour plots resulted in the identification of the optimum regions shown by the shaded area (Fig 5.7). The optimum regions were the square area of feed rate of 4.0-4.6kg/hr and peanut flour of 31.0-42.5%, and the area encompassing the linear line of feed rate of 4.6-6.0kg/hr and peanut flour from 42.5% to 37.0% until intercept of the minimum contour line of the degree of gelatinization (71.17) and followed the line to peanut flour of 32%. The optimum conditions should provide products with relatively high degree of gelatinization, low bulk density, and high volume expansion ratio. The

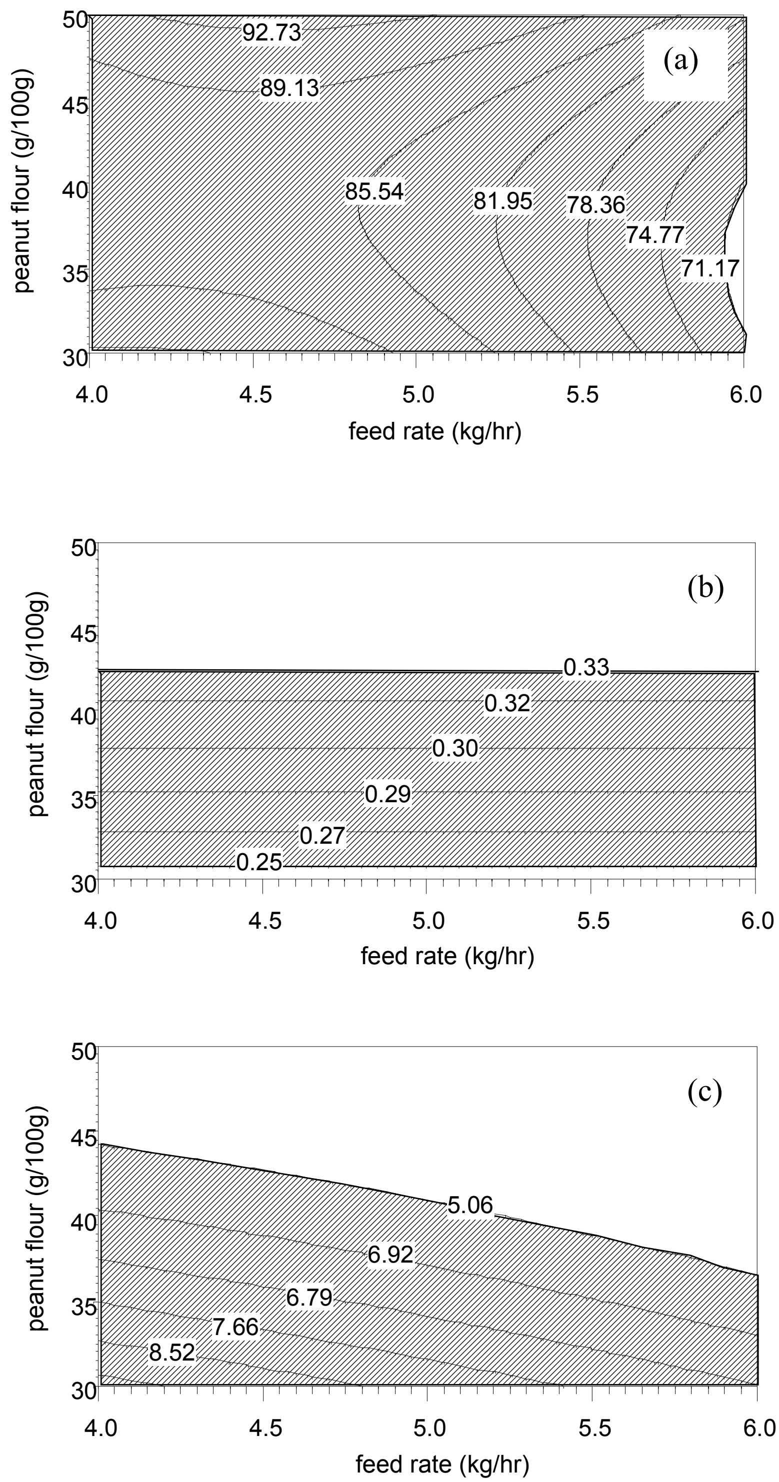

Fig 5.6. Contour plots of (a) degree of gelatinization, (b) bulk density, and (c) volume expansion ratio as a function of peanut flour (%) and feed rate (kg/hr) at the screw speed of 300rpm

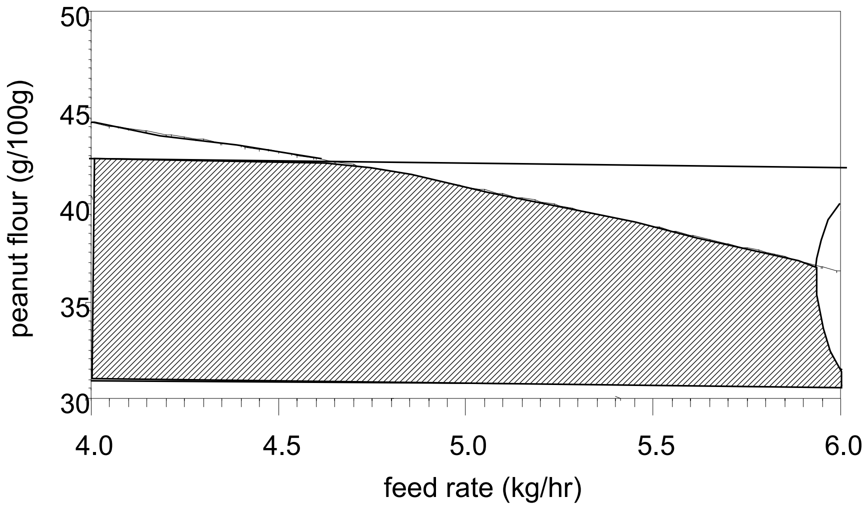

Fig 5.7. Superimposed contour plots of degree of gelatinization, bulk density, and volume expansion ratio for the peanut-based extruded snack products as a function of peanut flour and feed rate. The optimum regions were the square area of feed rate of 4.0-4.6kg/hr and peanut flour of 31.0-42.5%, and the area encompassing the linear line of feed rate of 4.6-6.0kg/hr and peanut flour from 42.5% to 37.0% to intercept of the contour line of the minimum degree of gelatinization (71.17) and followed to peanut flour of 32%

preferred higher volume expansion ratio values occurred in the same regions as the low predicted values for bulk density and high for the degree of gelatinization. The result from this study showed that formulation and extrusion condition affected degree of gelatinization of the half-products, and bulk density and volume expansion ratio of the finished products.

Relationship between Physical Properties and Sensory Evaluation

Relationship between Physical Properties and Consumer Acceptance Test: Degree of gelatinization and volume expansion ratio affected significantly to the attributes of overall liking and color in consumer acceptance test (Table 5.8). All physical properties except bulk density were found to be important to crispness. Degree of gelatinization and thickness of half-products had a relationship with texture in consumer test.

Relationship between Physical Properties and Descriptive Analysis: Table 5.9 shows the relationship between physical properties and the attributes of descriptive analysis. For the appearance, degree of gelatinization affected to the brown color, roughness, and puffiness. Thickness of half-products had relationship with roughness. Bulk density and volume expansion ratio were found to be important to brown color, roughness, and puffiness. For the aromatics and taste, bulk density only had a relationship with bitter. For the texture, degree of gelatinization was important to the hardness. Degree of gelatinization and bulk density affected significantly to the crunchiness and fracturability. All physical properties except volume expansion ratio were found to affect to the persistence of crunchiness. Whereas, all physical properties except thickness of half-product affected to the persistence of fracturability. There was

Table 5.8. Significant correlations between the attributes of consumer acceptance test and physical properties of peanut-based extruded snack products

attributes	physical properties			
	degree of gelatinization	thickness of half-products	bulk density	volume expansion ratio
overall liking	0.063***	ns	ns	-0.166**
color	-0.392*	ns	ns	7.658**
crispness	-2.356**	-49.986*	ns	22.319*
texture	0.065***	0.311*	ns	ns

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Table 5.9. Significant correlations between the descriptive attributes and physical properties of peanut-based extruded snack products

descriptive attributes	physical properties: degree of gelatinization	thickness of half-products	bulk density	volume expansion ratio
Appearance				
brown color	-0.339^{***}	ns	0.213^{***}	-0.296^{***}
roughness	-0.787^{**}	0.675^{*}	0.697^{**}	-0.729^{*}
porosity	ns	ns	ns	ns
puffiness	-0.314^{***}	ns	0.206^{***}	-0.284^{***}
Aromatics & Taste				
bitter	ns	ns	0.638^{*}	ns
Texture				
roughness	ns	ns	ns	ns
hardness	-1.217^{*}	ns	ns	ns
crispness	ns	ns	ns	ns
crunchiness	-2.825^{*}	ns	0.953^{***}	ns
fracturability	-0.532^{**}	ns	0.47^{***}	ns
persistence of crunchiness	0.329^{**}	0.763^{*}	0.545^{*}	ns
persistence of fracturability	-0.315^{**}	ns	0.217^{*}	-0.38^{**}

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

no significant relationship found between physical properties and the attributes of roughness and crispness in descriptive analysis.

CONCLUSIONS

It was demonstrated that indirectly, puffed snack products could be made from combinations of rice flour and up to 50% partially defatted peanut flour (12% fat) by extrusion processing. The level of peanut flour was the most responsible for the quality of half-product and fried puffed products, followed by feed rate. Screw speed had the least significant effect on the physical properties of half-product and final puffed snack products indicating that the formulations and extrusion processing conditions could be manipulated to produce desirable products. The physical properties of indirectly, puffed snack food could be effectively optimized using Response Surface Methodology (RSM). The optimum area was identified as the square area of feed rate of 4.0-4.6kg/hr and peanut flour of 31.0-42.5%, and the area encompassing the linear line of feed rate of 4.6-6.0kg/hr and peanut flour from 42.5% to 37.0% until intercept of the contour line of the minimum degree of gelatinization (71.17) and followed the line to peanut flour of 32%. Building regression models and generating response surfaces and contour plots would be effective in describing the complexity of the preparation of peanut-based extruded snack foods with the different variables used.

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SECTION VI

CELLULAR STRUCTURE OF PEANUT-BASED EXTRUDED SNACK PRODUCTS USNING SCANNING ELECTRON MICROSCOPY (SEM)

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ABSTRACT

Expanded snacks were prepared by deep-fat frying half-products produced by extruding mixtures of partially, defatted peanut flour (12% fat) and rice flour using a co-rotating, twin-screw extruder. The cellular structure and cell wall characteristics of expanded snack products were studied. The effects of three factors at three levels on microstructure were examined by using a Scanning Electron Microscopy (SEM): the three factors were the level of peanut flour (30, 40, and 50%), screw speed (200, 300, and 400rpm), and feed rate (4, 5, and 6kg/hr). Average cell size (mm^2) and the number of cells per unit area (cm^2) were determined from the interior cross-section area of the snack products. Increasing peanut flour resulted in less expanded snack products with smaller cell size resulting in an increase in the number of cells. The snack product extruded at the medium level of screw speed (300rpm) produced larger cells, and consequently decreased the number of cells. Average cell size and the number of cells affected by feed rate were relatively variable depending on the screw speed and the amount of peanut flour.

INTRODUCTION

Crispy food products have increased their impact in the food market in the last two to three decades as they provide energy, comfort and pleasure to consumers, and their popularity is expected to increase in coming years (Bouvier et al. 1997; Guraya and Toledo 1996). Among the "sensory acceptability factors", appearance, flavor, and texture, texture is certainly the most important descriptor to qualify crispy products (Bourne, 1982). The texture attributes of crispness and crunchiness are the most important descriptors making crispy snacks and low moisture, high starch snack foods popular among consumers (Bouvier et al. 1997). These properties relate to brittleness and fracturability, as the structure of crispy products tends to collapse with brittle fracture and a rapid decay of the force after fracture: this occurs with very low shear strength and work of mastication (Cristensen and Vickers 1981; Seymour and Hamann 1988).

Szczesniak (1963) classified textural characteristics into three main categories; mechanical characteristics, geometrical characteristics, and other characteristics referring mainly to moisture and fat contents of the food. Gao and Tan (1996a) related the texture of food products to their structural characteristics, such as cell size, cell density, and uniformity. They reported that expanded food products, three-dimensional structures of an intricate network of interconnected air cells and cell walls formed during the puffing process, are generally quite cellular, porous, and low in density. Further, their cellular structures are the most important texture-related geometric properties. Stanley (1986) suggested that food texture is a result of microstructure, which depends on the influence of physical forces on chemical components.

Mechanical properties are another important aspect of expanded food products. The mechanical properties are associated with mechanical strength and deformation, and related to their cellular structure (Gao and Tan 1996b). Many starch-based snack foods are inherently cellular and brittle, and these products exhibit a classical brittle failure mechanism as a consequence of their cellularity and lack of structural resiliency. They are described as "crispy / crunchy" because of a complex failure mechanism that involves the repetitive deformation and fracturing of the cell structure, specifically the individual cells and brittle cell walls (Barrett et al. 1994).

The high temperature – short time extrusion process has been used in the food industry to produce directly expanded crispy snack foods. These snacks vary in structural properties and mechanical properties depending on formulation and extrusion conditions. The extrusion process also has been used to make half-products, which will be further puffed in a hot air stream or by deep-fat frying. Puffing occurs when water within a heated material rapidly vaporizes to build-up an internal pressure adequate to expand the matrix of the heat softened solid (Blenford 1979). Characterization of cell size distribution and cell organization may help control the extrusion process so as to produce a desired and uniform extrudate products (Barrett et al.1992).

Scanning Electron Microscopy (SEM) is often used to analyze the internal geometrical structure of a food product such as cell size and number of cells per unit cross-sectional area, and/or surface appearance in details. Cell size distribution can indicate how finely or coarsely the material is subdivided (Gao and Tan 1996a). Gao and Tan (1996a,b) developed color image processing techniques to characterize surface and cross-section images of a yellow corn meal extrudate product, and they also measured the cell size and density using SEM photographs. They found that a number of image features could be used to describe the texture-related geometric properties, and the image features were highly correlated with the mechanical properties. Ryu and Walker (1994) used a scanning electronic microscopy to observe the cell structure of wheat flour extrudates produced with different compositions, and reported that the type of emulsifiers and the addition of sucrose and shortening powder significantly influenced the structural parameters. Tan et al. (1997) characterized the cellular structure of puffed corn meal extrudates using SEM images, and reported that a number of image features were found to be good indications of the cell distribution.

There are many advantages using the scanning electronic microscopy (SEM) compared to light microscopy and transmission electron microscopy. The SEM has a large depth of field defining the extent of the zone on a specimen, which appears acceptably in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instrument in research today (Peleg and Bagley, 1983).

Studies demonstrating the effects of extrusion processing on the textural and microstructure properties of extrudates have been reported. However, very little information has been published on the relationships between the extrusion conditions (screw speed and feed rate) and the particular ingredients featured in this study (peanut flour and rice flour) in reference to microstructure of puffed snack products. The objective of this study was to characterize the cellular structure of extruded snack products by altering the extrusion conditions and formulation of materials. Internal structure was characterized in terms of cell size distribution and cell density.

MATERIALS & METHODS

Materials

A mixture of peanut and rice flour was blended at three levels of peanut flour (30, 40, and 50%) to rice flour using a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY), and was extruded at three levels of feed rate (4, 5, and 6kg/hr) and screw speed (200, 300, and 400rpm) in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England). The temperature profiles of the extruder barrels was set to be 100, 120, 110, 95, and 80ºC from feed zone to die. The barrel temperatures of zone four and five was set blow 100ºC to prevent puffing of extrudates. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. Half-products were puffed by deep-fat frying at 200 ± 5ºC for 35-40sec in pure vegetable oil (The detailed procedure to produce half-products and final snack products is in Section II).

Scanning Electronic Microscopy (SEM)

The puffed snack products were carefully broken to expose an interior cross-section area and appropriately sized pieces were attached on aluminum stubs. In order to remove oil inside the snack samples, they were placed in the vacuum evaporator (Denton DV-502 A) running at –1000 millitorr overnight. The samples were coated with 50nm thick 60:40 gold palladium alloy by a Hummer X (Anatech Inc.) sputter coater. The cross section of snack samples was viewed using scanning electron microscopy (LEO 982 FE-SEM) running at 5-7 KeV acceleration.

SEM Images and Geometric Measurements

A scion image analyzer (Scion Co., Frederick, MD) was used to characterize the cell distribution of puffed snack products. Two structural parameters, cell size and the number of cells, were measured from the SEM photos (Gao and Tan 1996a). Upon measurement, calibration was done to convert number of pixels to square millimeters. The cell size of each cell (larger than the assigned cutoff of the area of 1mm^2) was measured from the cross-section image by tracing the circumference of each cell using a computer mouse. Examination of the SEM images indicated that the cell sizes differed among samples primarily for a few large cells. As it was mainly the sizes of a few large cells that varied considerably from one sample to another, the average of the three largest cells in a cross section was taken to represent the cell size. The size of the three largest cells was thus measured from the SEM images, converted into the cell area (mm^2), and averaged to serve as a representative cell area. The number of cells within a fixed image (12.0 mm^2) was counted manually to give cell density. The average cell size and the number of cells per unit area (cm^2) were calculated. Two sections of each product were analyzed by this technique.

Statistical Analysis

Experimental data was analyzed using Statistical Analysis System (SAS Institute, Inc., 1990). Regression analysis (PROC REG) was used to determine the behavior of the response variables in relation to the set of independent factors in the whole model. Independent factors were three different levels of peanut flour (30, 40, and 50%), screw speed (200, 300, and 400 rpm), and feed rate (4, 5, and 6 kg/hr). The dependent variables were the two cell structure parameters, which were average cell size and the number of cells per unit area. The significant formulation and/or extrusion operational factors and their interaction terms from the whole model were selected at 10% level of significance resulting in a reduced model. Regression analysis (PROC REG) was applied with the reduced model to fit second order polynomial models. These models included all linear and quadratic terms of the individual independent factors and all interaction terms (cross-product) of linear terms. Linear terms were always retained in the model when a quadratic or a cross-product term involving that linear term was included. Response Surface Methodology (RSM) was applied to determine the effects of the significant factors on the response surface. Predictive models were used to plot the response surface.

RESULTS & DISCUSSION

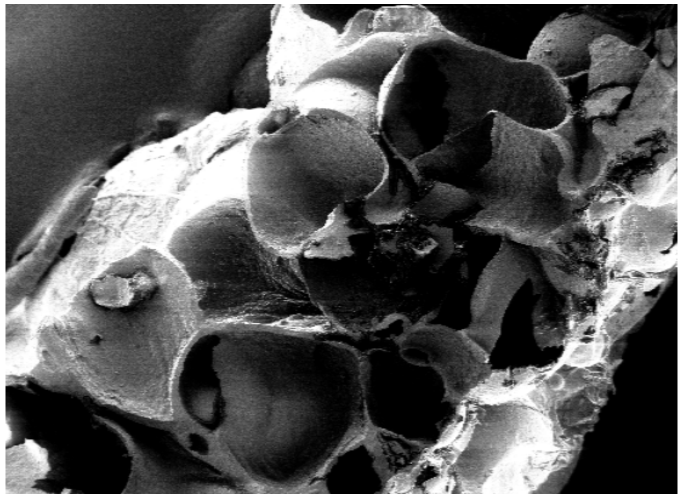
Microstructure of Snack Products

The SEM images, 432 × 432 pixels in $4 mm^2$, clearly revealed the detailed internal structure of the snack products (Fig 1, 2, and 3). The SEM images showed that there were differences in the cellular structure among them. The cell shape was roughly circular and exhibited little discernable variations from one sample to another. Snack products were distinguishable by their internal structure, and the geometric differences were predominantly in cell area and cell density.

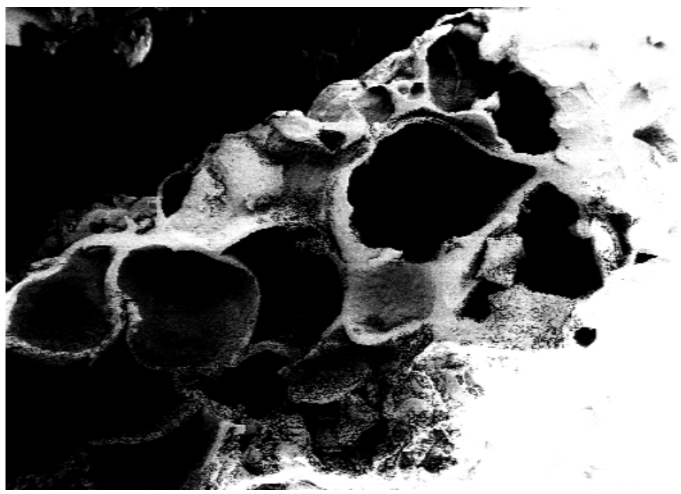
The snack products had different cell sizes and distributions mostly varying to the level of peanut flour, and slightly screw speed and feed rate. The effects of the level of peanut flour extruded at a constant screw speed (300rpm) and feed rate (4kg/hr) on the internal structure of the snack products are shown in Fig 6.1. Increasing the level of peanut flour resulted in a less expanded, more compact texture in final snack products. The 50%peanut flour snack product had smaller cells and thicker cell walls than those 30% peanut flour products. In the previous study of physical properties of peanut-based extruded snack products, the volume expansion ratio (VER) was measured and the results showed that the half-products extruded with lower level of peanut flour expanded more than those higher levels of peanut flour. The SEM picture shows that in general, the more expanded snack products would have larger cells with thinner cell walls than the less expanded products.

Fig 6.2 shows the effects of screw speed at a constant peanut flour (50%) and feed rate (4kg/hr) on the cell structure. The extruder screw sequentially conveys and heats food ingredients through frictions, and works them into a plasticized mass in a tightly fitting barrel. Increasing or decreasing screw speed affects the degree of barrel fill, residence time, and shear stress on the extruded materials resulting in different cell structure on the extrudates. The snack products processed at screw speed of 200 and 300rpm produced larger cell size and thinner cell walls compared to those processed at screw speed of 400rpm. The physical properties of peanut-based snack products revealed that the volume expansion ratio decreased with increasing screw speed. It could be explained that the reduced residence time by increasing screw speed, especially in low temperature profiles to produce indirectly puffed extrudates, might be not enough to cause much starch gelatinization for half-products due to a shorter processing time.

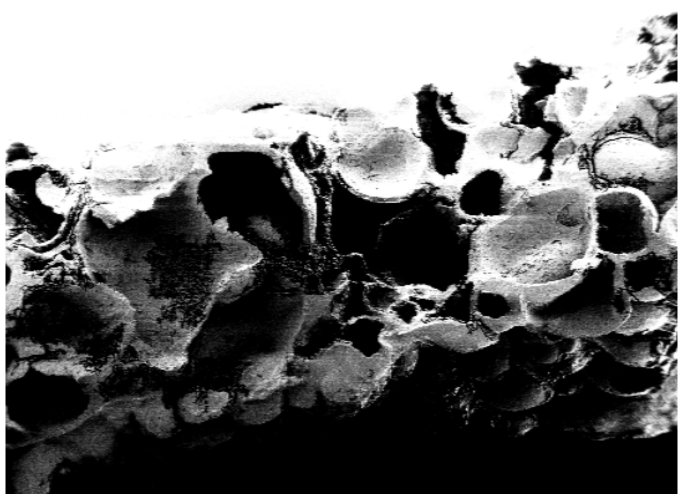
Fig 6.1. Scanning Electron Micrographs of peanut-based extruded snack products at different level of peanut flour (%) at constant screw speed of 300rpm and feed rate of 4kg/hr (a) 30% peanut flour, (b) 40% peanut flour, and (c) 50% peanut flour



(a)

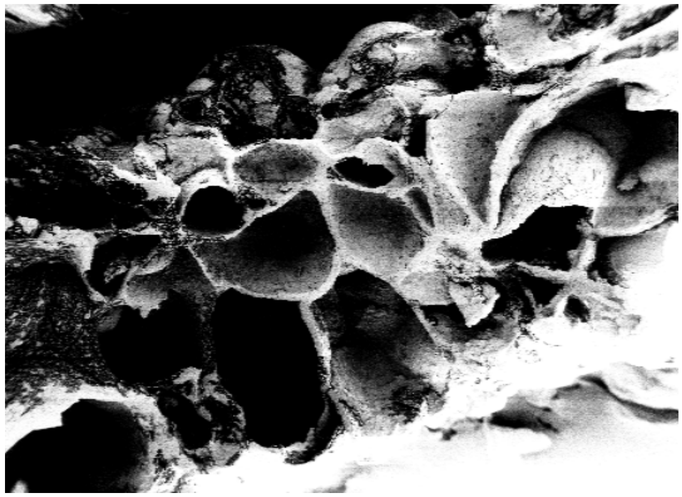


(b)

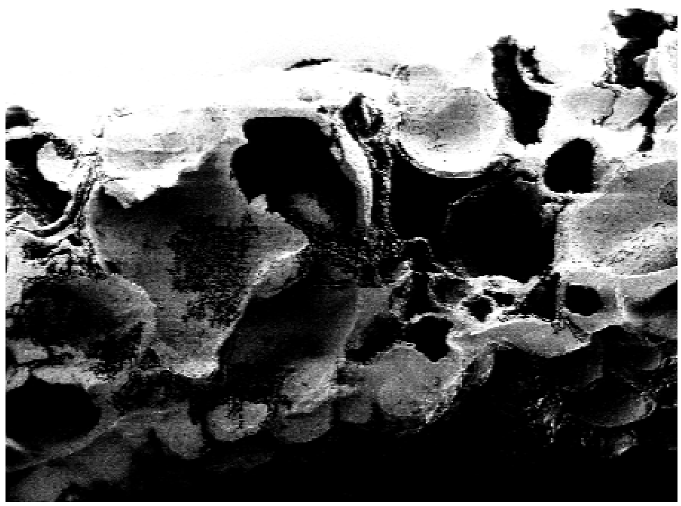


(c)

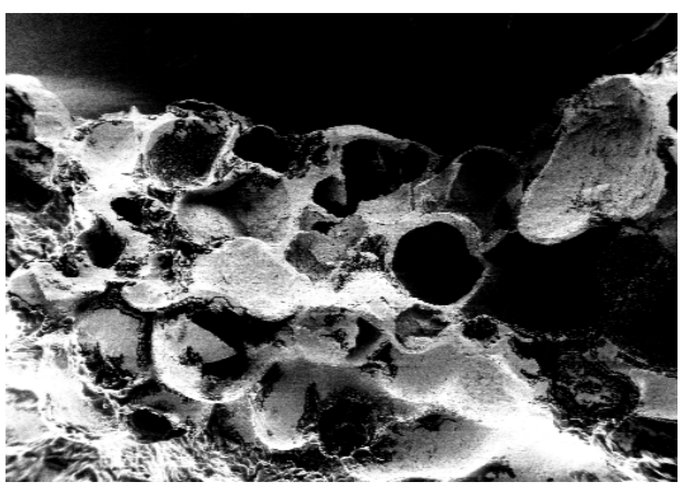
Fig 6.2. Scanning Electron Micrographs of peanut-based extruded snack products at different level of screw speed (rpm) at constant peanut flour of 50% and feed rate of 4kg/hr (a) screw speed of 200rpm, (b) screw speed of 300rpm, and screw speed of 400rpm



(a)



(b)



(c)

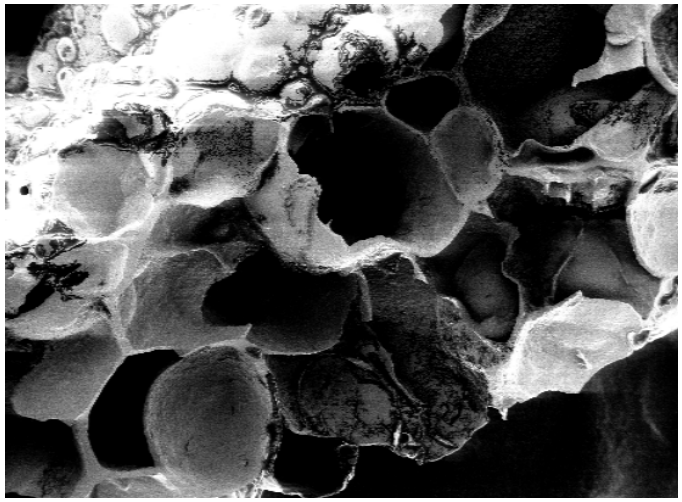
These less gelatinized half-products resulted in less expanded snack products compared to those much gelatinized half-products after deep-fat frying (Anderson et al. 1969; Ibanoglu et al., 1996). In addition, the products extruded at screw speed of 200 and 300rpm had fewer cells per unit area (cm^2) than those extruded at screw speed of 400rpm. Jin et al. (1995) observed that the corn meal extrudates processed at a lower screw speed had thinner cell walls and larger air cell sizes than those extrudates processed at higher screw speeds. Della et al. (1987) reported that increasing the screw speed increased the shear rate and the potential for mechanical damage to food molecules. These damaged starches were characteristically less cohesive than gelatinized, undamaged starch. Consequently, they expanded less creating products with small pores.

Feed rate also affected on the internal structure of the snack products. Fig 6.3 shows the microstructure of snack products extruded at different feed rates at constant peanut flour of 30% and screw speed of 200rpm. The microphotographs show that average cell area were similar among three products, but the cell walls were slightly thicker when the materials were extruded at higher level of feed rate. The same explanation can be applied to describe this result. At constant screw speed, as the feed rate increased, especially in the low temperature settings, the high amount of starch in the mixture might not be fully gelatinized for puffing resulting in thicker cell walls compared to those less starch mixtures.

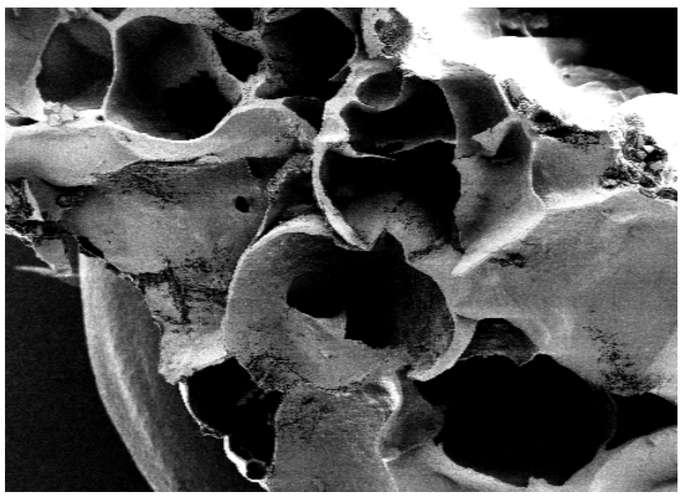
Average Cell Size

Fig 6.4 shows the cell average area for the three biggest cells of peanut-based snack products extruded at three different levels of peanut flour, feed rate, and screw speed.

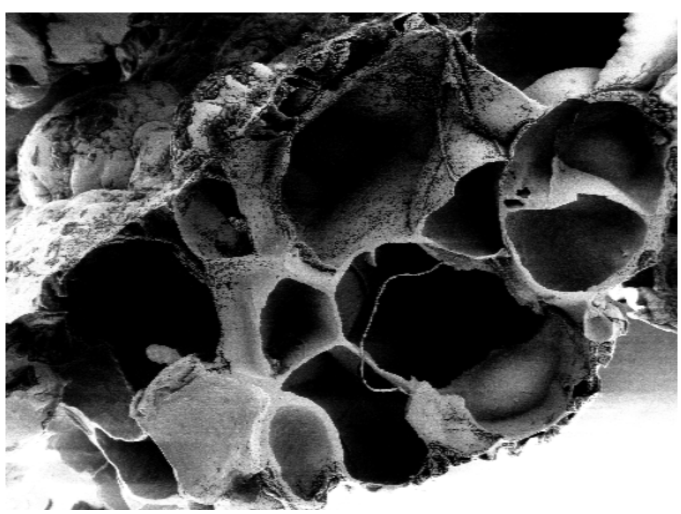
Fig 6.3. Scanning Electron Micrographs of peanut-based extruded snack products at different level of feed rate (kg/hr) at constant peanut flour of 30% and screw speed of 200rpm (a) feed rate of 4kg/hr, (b) feed rate of 5kg/hr, and (c) feed rate of 6kg/hr



(a)

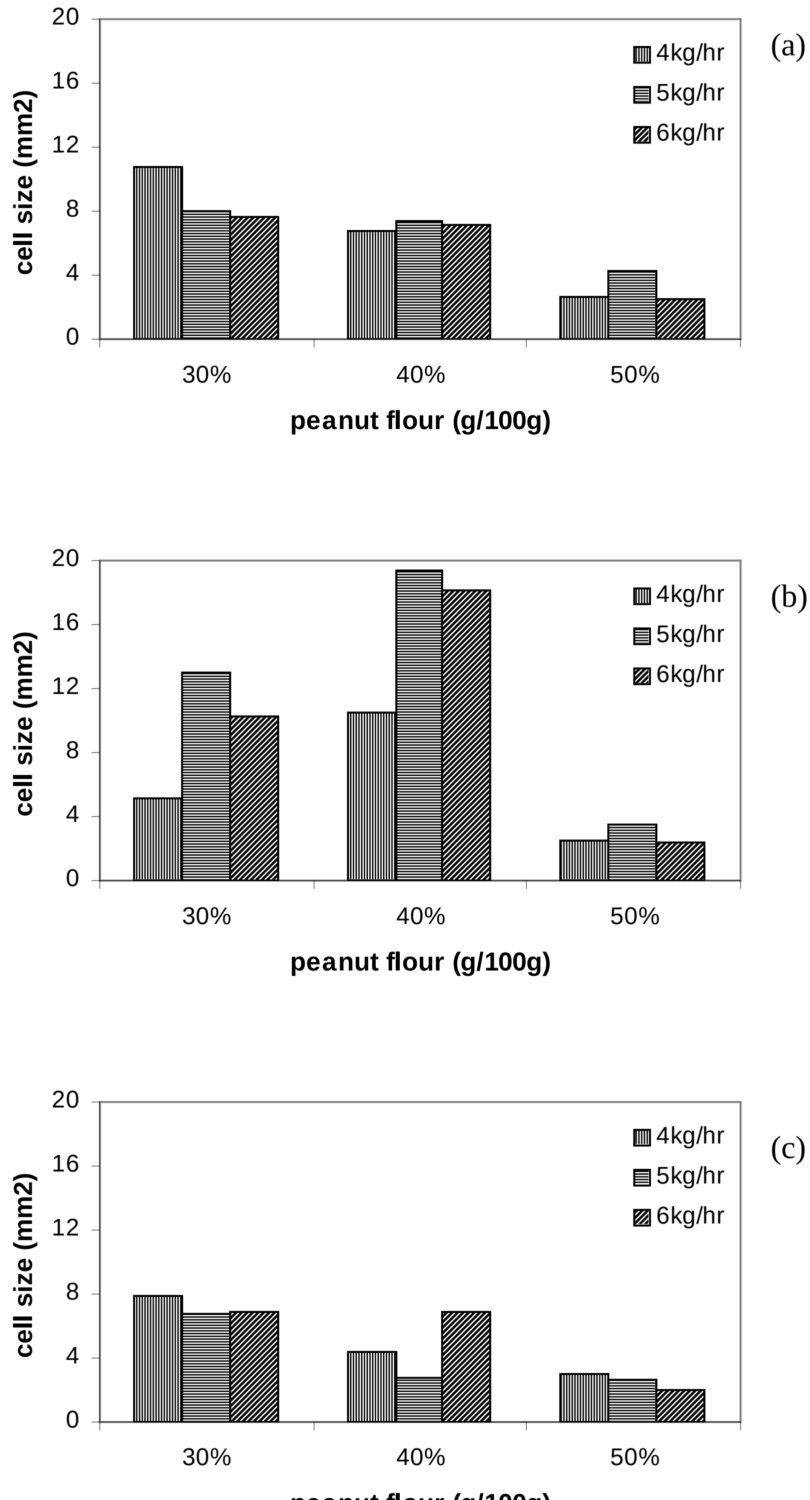


(b)



(c)

Fig 6.4. The effects of peanut flour (%) and feed rate (kg/hr) on average cell area (mm^2) of peanut-based snack products extruded at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm



20
16
12
8
4
0
cell size (mm2)
4kg/hr
5kg/hr
6kg/hr
(a)
30%
40%
50%
peanut flour (g/100g)
(b)
(c)

The cell size was relatively different between snack products extruded with peanut flour of 30% and 40% and those containing 50% peanut flour: generally, cell size increased with decreasing peanut flour. The averaged cell size of the snack products extruded with peanut flour levels of 30% and 40% varied considerably with screw speeds and feed rates, but varied slightly for 50% peanut flour snack product. The snack products extruded at low and medium screw speed (200 and 300rpm) produced larger cells compared to those extruded at 400rpm.

For the snack product containing 30% peanut flour, when the material was extruded at screw speed 200rpm, the cell size of low feed rate (4kg/hr) snack product was bigger than the other two (5 and 6kg/hr) products. However, at screw speed of 300rpm, the cell size at medium feed rate (5kg/hr) was bigger than the others (4 and 6kg/hr), and at screw speed of 400rpm, there was little difference between feed rates. For the snack product containing 40% peanut flour, there was a relatively large variation in cell size as a result of screw speed. When the mixture was extruded at the medium level of screw speed (300rpm), the final product exhibited the biggest cell size followed by product processed at 200rpm and at 400rpm. The averaged largest cell area (19.33mm^2) was found in the snack product containing 40% peanut flour extruded at a feed rate of 5kg/hr and screw speed of 300rpm. On the other hand, the highest peanut flour (50%) snack products had small cells with averaged cell area lower than 4.0mm^2 varied very slightly with screw speed and feed rates. The smallest cell area (2.06mm^2) was found in the snack product containing 50% peanut flour extruded at a feed rate of 6kg/hr and screw speed of 400rpm.

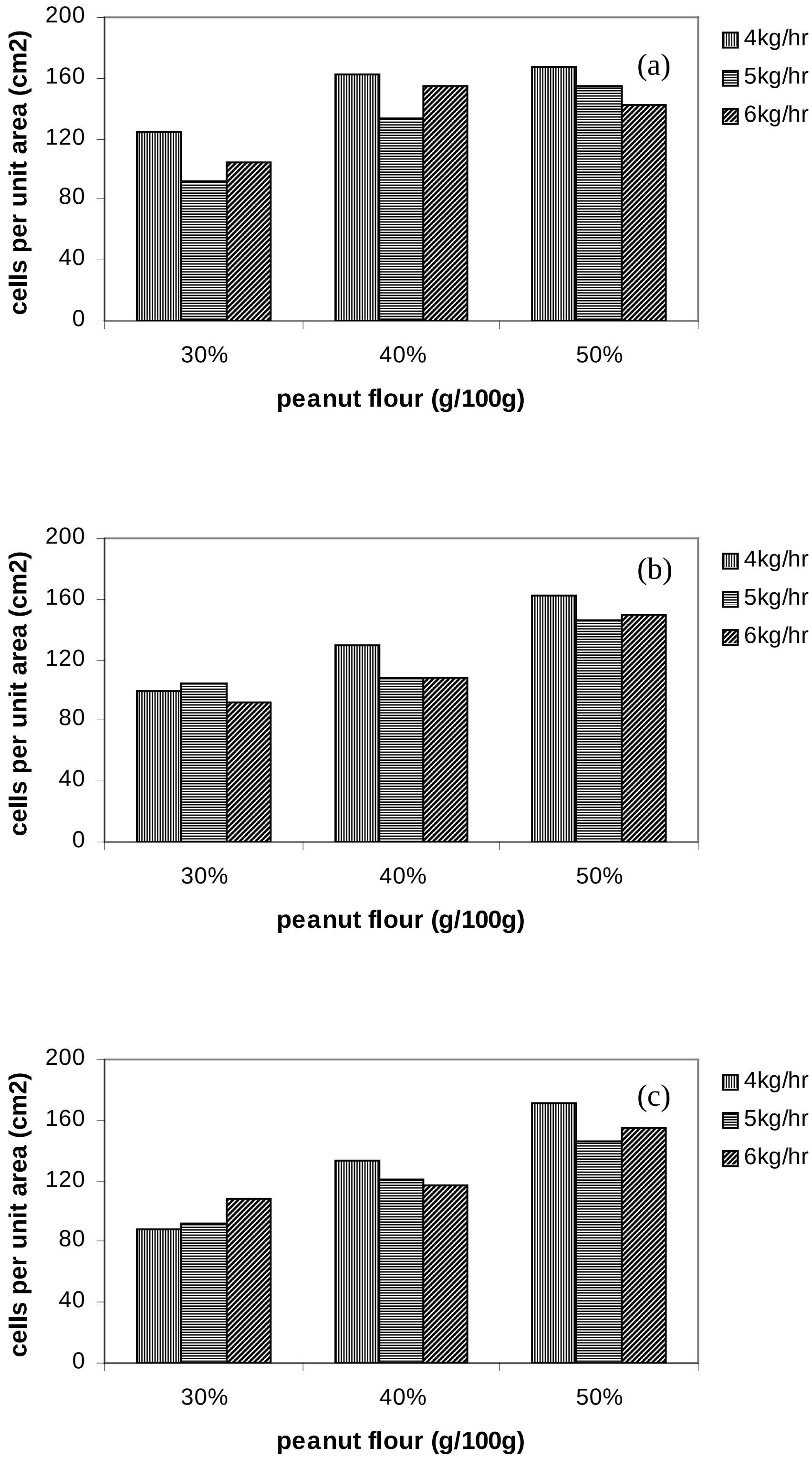
In the previous study of physical properties of peanut-based extruded snack products, the volume expansion ratio (VER) was affected mainly by the amount of peanut flour followed by feed rate and screw speed. The cell size may be positively related to the volume expansion ratio: increasing the level of peanut flour significantly decreased the volume expansion ratio resulting in small cell size.

The cellular structure of snack type foods produced by extrusion processing has been studied by some researchers. Stanley (1986) examined the texture of fabricated foods produced by extrusion processing, and reported that porosity increased with increasing expansion and decreasing breaking strength, and those two parameters (expansion and breaking strength) were negatively correlated. Barrett and Peleg (1992) measured the cell size and cell density of directly puffed corn-based extrudates produced by varying extrusion moisture and screw speed and by addition of rice flour, citric acid, tricalcium phosphate, sodium bicarbonate, and gluten. They also measured the mechanical properties during compression. They reported that, in the case of the pure corn extrudates, an increase in cell density was coupled with decreased cell size indicating that the structure was "filled in" and generally less porous (with thicker cell walls) as cell size decreased. Thus, the strength of the extrudates increased with smaller cells and more dense structure. However, the other samples, which contained additives, did not show the same relationship between cell size and density. Each additive except bicarbonate reduced both density and average cell size.

Number of Cells

The number of cells per unit area (cm^2) is shown in Fig 6.5. It appeared the number of cells was slightly related to peanut flour positively, but inversely related to screw

Fig 6.5. The effects of peanut flour (%) and feed rate (kg/hr) on the number of cells per unit area (cm^2) of peanut-based snack products extruded at (a) screw speed of 200rpm, (b) screw speed of 300rpm, and (c) screw speed of 400rpm



(a)
(b)
(c)
cells per unit area (cm2)
0
40
80
120
160
200
30%
40%
50%
peanut flour (g/100g)
4kg/hr
5kg/hr
6kg/hr

speed. The previous study of physical properties of peanut-based extruded snack products revealed that the half-products extruded with the lowest peanut flour (30%) at the lowest feed rate (4kg/hr) showed the high degree of gelatinization resulting in the lower bulk density and higher volume expansion ratio of expanded snack products. Increasing the level of peanut flour and feed rate significantly increased the bulk density of puffed snack products, which indicated that increasing peanut flour and feed rate resulted in a more dense final snack products. This result may be correlated with an observation of the number of cells. The number of cells slightly increased with increasing the level of peanut flour regardless of screw speed. It was observed that when the 30% peanut flour mixture was extruded at screw speed of 400rpm, the number of cells was slightly lower than those at screw speed of 200 and 300rpm. The cell size data showed that the cell size decreased at highest screw speed (400rpm), which might be due to the lower expansion of final snack products. It can be assumed that the snack product extruded at the high screw speed produced the small cell size with thicker cell walls, and these thick cell walls could cause a decrease in the number of cells per unit area. However, there was no significant difference in number of cells with increasing or decreasing feed rate regardless of screw speed and peanut flour. It also could be explained that feed rate might be the main reason to build the cell walls thicker. The highest number of cells per unit area was observed in the product extruded with 50% peanut flour and 4kg/hr feed rate regardless of screw speed. Whereas the lowest number of cells was given to the product extruded with 30% peanut flour and 4 and 5kg/hr feed rate.

Effects of Variables for Cell Structure

The effects of formulation (the level of peanut flour) and extrusion conditions (screw speed and feed rate) for cellular structure parameters, average cell size and the number of cells per unit area (cm^2) are shown in Table 6.1. Regression analysis indicated that the fitted quadratic model accounted for 69.5% and 75.1% of the variation in the experimental data for average cell size and the number of cells, respectively. The linear and quadratic terms of the model for peanut flour had a significant effect on the average cell size at 5% and 1% level of significance, respectively, but no effect on the number of cells per unit area. The screw speed and feed rate had a linear effect on both cell structure parameters at 10% level of significance for average cell size and 5% level of significance for the number of cells. The quadratic effects of screw speed and feed rate were found to be significant on cell size at 1% level of significance, and on the number of cells at 5% level of significance. However, no cross-product effects were found to be significant for either cell structure parameter at 10% level of significance in the model. The predictive models for average cell size (Y_1) and the number of cells (Y_2) were:

$$Y_1 = -110.10 + 2.662X_1 + 0.228X_2 + 16.263X_3 - 0.037X_1^2 - 0.0004X_2^2 - 1.557X_3^2 \quad (R^2 = 0.606)$$

$$Y_2 = 379.324 + 2.708X_1 - 0.599X_2 - 103.325X_3 + 0.0009X_2^2 + 0.731X_3^2 \quad (R^2 = 0.722)$$

where, X_1 = peanut flour (%)

X_2 = screw speed (rpm)

X_3 = feed rate (kg/hr)

Table 6.1. Analysis of variance for cell structure parameters

	regression coefficients	
variables	cell size[a]	no. of cell[b]
intercept	-115.962	613.936
PF	2.824**	-0.980
SS	0.222*	-1.743**
FR	18.031*	-148.346**
PF × PF	-0.037***	-0.021
SS × SS	-0.0004***	0.0009**
FR × FR	-1.557***	9.731**
PF × SS	0.0001	0.024
PF × FR	-0.047	0.865
SS × FR	-0.0006	0.201
PF × SS × FR	0.00003	-0.004
R^2	0.695	0.751

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
**significant at $p \leq 0.10$
[a]number of cells per unit area (cm^2)
[b]average cell area
PF = peanut flour (%)
SS = screw speed (rpm)
FR = feed rate (kg/hr)

The models provide the information about the effects of each factor on the cell structure parameters, average cell size and the number of cells. The contour plots in Fig 6.6 and 6.7 are based on the above models with three independent factors. The level of each factor was kept constant at peanut flour of 30%, screw speed of 300rpm, and feed rate of 4kg/hr when the effect of the other two variables was shown. Fig 6.6 shows the contour plots of the average cell size as a function of peanut flour and screw speed (a), peanut flour and feed rate (b), and screw speed and feed rate (c). From Fig 6.6-a and b, the contour plots indicated that the effect of screw speed was more significant than feed rate: the maximum average cell size occurred at peanut flour of 30-40%, screw speed of 250-320rpm, and feed rate of 4.6-5.6kg/hr. Fig 6.6-c showed a similar pattern that at the fixed peanut flour of 30% the maximum average cell size was at the screw speed of 250-320rpm and feed rate of 4.7-5.3kg/hr. Generally, increasing peanut flour from 30 to 40% increased the cell size, but from 40-50% the average cell size decreased. Fig 6.7 shows the contour plots of the number of cells per unit area (cm^2) as a function of peanut flour and screw speed (a), peanut flour and feed rate (b), and screw speed and feed rate (c). The contour plots demonstrated that the peanut flour affected more significantly than feed rate and screw speed (Fig 6.7-a and b). At the constant feed rate of 4kg/hr (Fig 6.7-a) and screw speed (Fig 6.7-b), the number of cells increased with increasing peanut flour. Whereas, at the constant peanut flour of 30% (Fig 6.7-c) the number of cells increased with decreasing screw speed and feed rate. It was observed that the differing formulations and extrusion processing conditions produced products with different cell structure features, which in turn may lead to different textural perceptions. Jin et al. (1995) reported that scanning electron microscopy revealed that increasing fiber, sugar

Fig 6.6. Contour plosts for average cell size (mm^2) of peanut-based snack products extruded with peanut flour of 30% at screw speed of 300rpm and feed rate of 4kg/hr (a) the effect of peanut flour and screw speed
(b) the effect of peanut flour and feed rate
(c) the effect of screw speed and feed rate

Fig 6.7. Contour plots for the number of cells per unit area (cm^2) of peanut-based snack products extruded with peanut flour of 30% at screw speed of 300rpm and feed rate of 4kg/hr (a) the effect of peanut flour and screw speed
(b) the effect of peanut flour and feed rate
(c) the effect of screw speed and feed rate

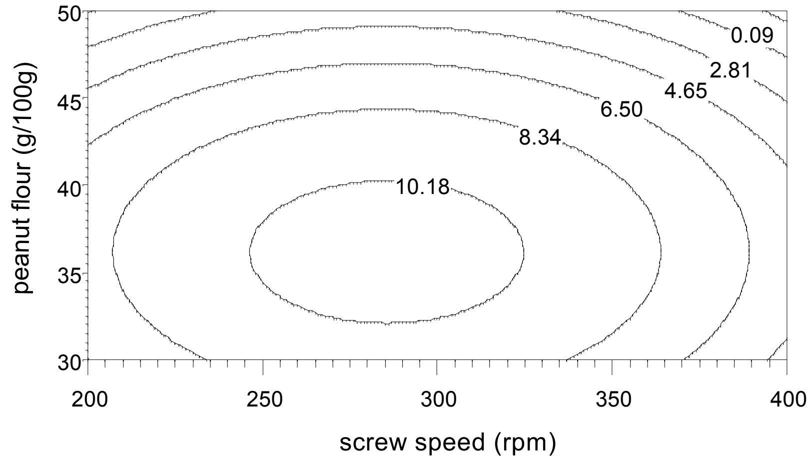


Fig 6-a

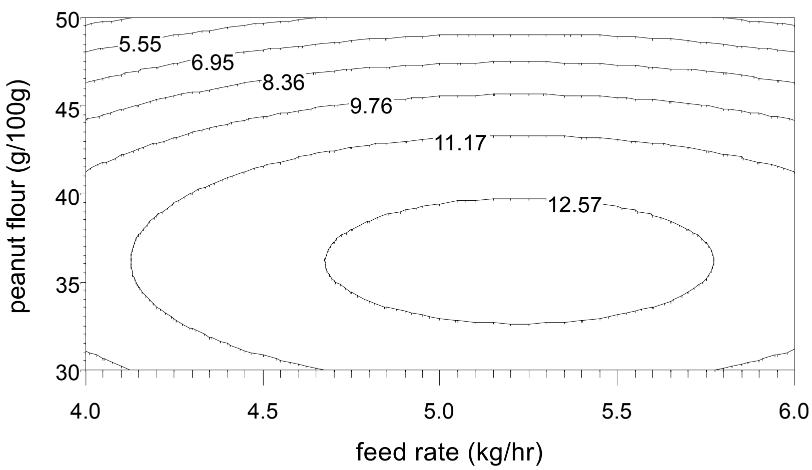


Fig 6-b

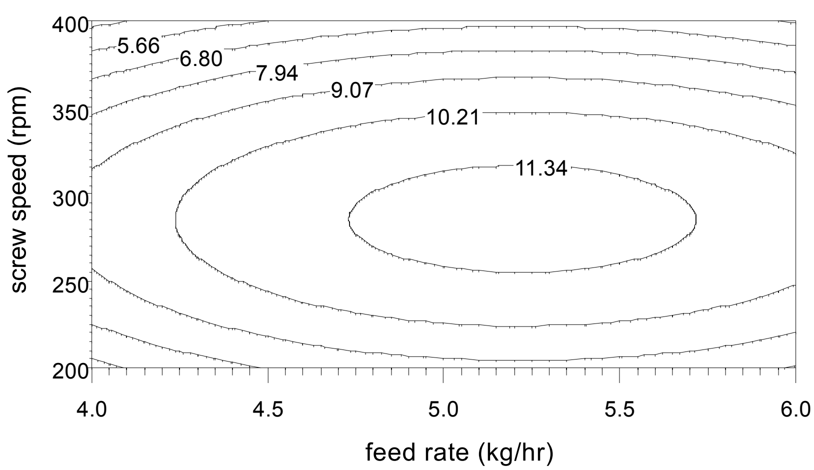


Fig 6-c

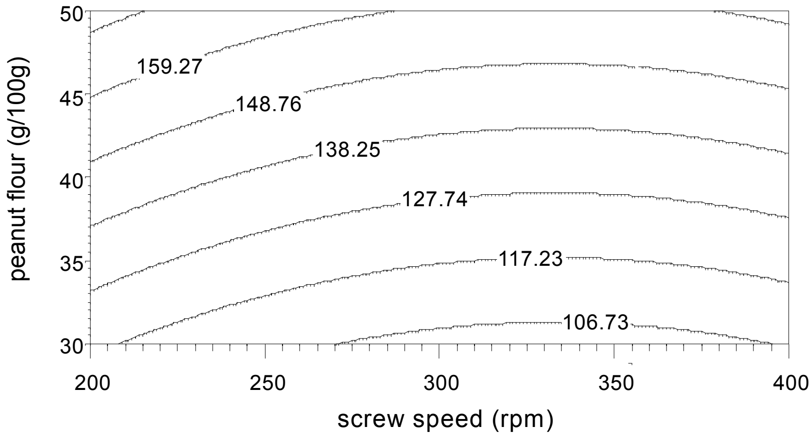


Fig 7-a

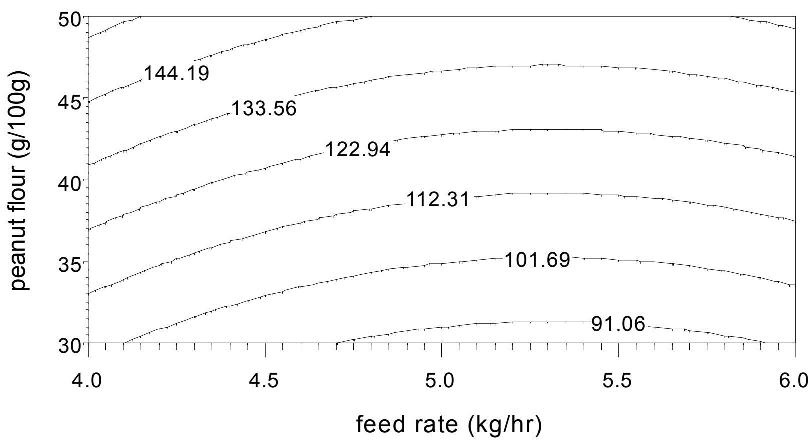


Fig 7-b

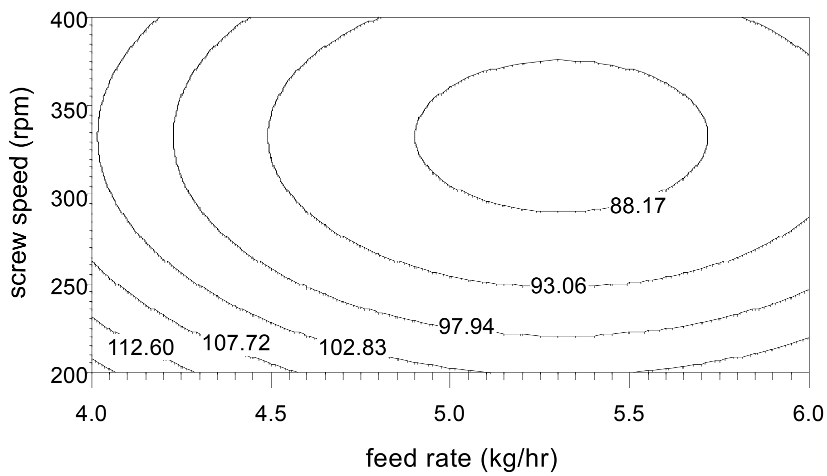


Fig 7-c

content, and screw speed resulted in less expanded extrudates with smaller air cell size and thicker cell walls. Li and Lee (1996) reported that the added cysteine during twin-screw extrusion produced the extrudates, in which the cell size decreased and the cell wall thinned. Lue et al. (1990) extruded corn meal mixed with dietary fiber, and examined their microstructure. They reported that the degree of extrudate expansion was dependent on the source and amount of dietary fiber, and was associated with the size of air cells inside extrudates and with the external structure of products. They also examined the effects of sugar on the internal structure of corn meal extrudates, and reported that the extrudates processed at lower sugar levels had thinner cell walls and larger air cell sizes than those processed at higher sugar levels. In addition, Guy (1985) suggested that since bran interferes with bubble expansion, which reduces extensibility of cell walls and causes premature rupture of steam cells at a critical thickness, steam could easily be lost during the flashing process. Hence the presence of bran would prevent formulation of large cells. Tan et al. (1997) characterized the cellular structure of puffed corn meal extrudates from SEM images, and found the image features were a good indicator of the cell distribution.

Relationship between Cellular Structure and Sensory Evaluation

Relationship between Cellular Structure and Consumer Acceptance Test: the both parameters of cellular structure, average cell size and the number of cells, affected significantly to the attributes of overall liking, color, crispness, and texture in consumer acceptance test (Table 6.2).

Relationship between Cellular Structure and Descriptive Analysis: Table 6.3 shows the relationship between cellular structure and the descriptive sensory analysis.

Table 6.2. Significant correlations between the attributes of consumer acceptance test and cellular structure of peanut-based extruded snack products

attributes	parameters of cellular structure	
	average cell size	number of cells
overall liking	-2.417***	-58.796***
color	0.208**	8.161**
crispness	0.04***	1.462***
texture	0.029***	1.179***

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Table 6.3. Significant correlations between the descriptive attributes and cellular structure of peanut-based extruded snack products

descriptive attributes	cell structure parameters: average cell size	cell structure parameters: number of cells
Appearance		
brown color	ns	ns
roughness	ns	0.734**
porosity	ns	0.738***
puffiness	0.616***	0.439***
Texture		
roughness	ns	0.362**
hardness	ns	ns
crispness	ns	0.725***
crunchiness	-0.326***	0.563***
fracturability	ns	-0.129*
persistence of crunchiness	0.231*	ns
persistence of fracturability	0.682***	0.331***

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq$

Table 6.4. Significant correlations between the cellular structure and physical properties of peanut-based extruded snack products

physical properties	parameters of cellular structure: average cell size	number of cells
degree of gelatinization	-0.526***	0.279***
thickness of half-products	-0.009***	ns
bulk density	0.571***	-0.281**
volume expansion ratio	-0.098***	ns

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

For appearance, average cell size had a relationship with puffiness, whereas the number of cells was found to be important to roughness, porosity, and puffiness. For texture, average cell size was important to crunchiness, persistence of crunchiness, and persistence of fracturability. Whereas the number of cells affected to the roughness, crispness, crunchiness, fracturability, and persistence of fracturability.

Relationship between Cellular Structure and Physical Properties: The physical properties of the degree of gelatinization, thickness of half-products, bulk density, and volume expansion ratio significantly affected to the average cell size (Table 6.4). Whereas, the degree of gelatinization and bulk density were found to be important to the number of cells.

CONCLUSIONS

The composition of extruded materials and extrusion processing conditions affected the degree of expansion of the end products. One of the requisites for extrusion puffed products is the starch material to be gelatinized to expand resulting in forming numerous air bubbles. The puffed air bubbles differentiate the cell structure of the products extruded at different formulations and extrusion processing conditions. The microstructure of the peanut-based extruded snack products indicated that the formulations and extrusion conditions affected to the average cell size (mm^2) and the number of cells per unit area (cm^2). Contour plots indicated that at a fixed feed rate of 4kg/hr increasing peanut flour from 40 to 50% and screw speed from 350 to 400 rpm resulted in significantly decreased average cell size resulting in increasing the number of cells. The maximum average cell size occurred at peanut flour of 35-40%, screw speed of 250-320rpm, and feed rate of 5.0-5.5kg/hr. Feed rate had a relatively little effect on the average cell size. The peanut flour affected more significantly than feed rate and screw speed on the number of cells per unit. At the constant feed rate and screw speed, the number of cells increased with increasing peanut flour. Whereas at the constant peanut flour, decreasing screw speed and feed rate resulted in increasing the number of cells: it could be explained that increasing and feed rate might be resulted in small average cell size and thick cell walls. It was observed that the differing formulations and extrusion processing conditions produced products with different cell structure features, which in turn may lead to different textural perceptions. Moreover, the information of cellular structure could be applied to predict and control the functional properties and textural characteristics of extruded products.

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SECTION VII

CHARACTERIZING CRISPNESS OF PEANUT-BASED EXTRUDED SNACK PRODUCTS BY ACOUSTICAL AND MECHANICAL PROPERTIES

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ABSTRACT

Extrudate pellets were prepared by extruding the blends of partially defatted peanut flour (12% fat) and rice flour combined at different ratios using a co-rotating twin-screw extruder. The extrudates were dried to obtain half-products with 11-12% moisture contents, and expanded by deep-fat frying at 200ºC for 35-40sec. The effects of peanut flour and feed rate were investigated by acoustical and mechanical properties. Acoustical signals were characterized by recording the sound generated during compressing products. Force-deformation curves of mechanical measurement were recorded for texture changes induced by the level of peanut flour and feed rate. The frequencies and amplitude of sound were identified and quantified from acoustical signals by a Fast Fourier Transformation (FFT). The peak frequencies ranged from 5.5kHz to 6.5kHz with different intensities. The power spectra density (PSD) indicated that the snack product extruded with 30% peanut flour produced three times more acoustical energy than those extruded with 50% peanut flour. The peak force and the mechanical energy at the first peak from force-deformation curve decreased with decreasing the level of peanut flour: 30% peanut flour snack product was mechanically weaker than 50% peanut flour product.

INTRODUCTION

Most low moisture products such as breakfast cereals, wafers, biscuits, and puffed snacks have a crispy texture, which is a complex property, combining mechanical, macro-structural, and acoustic characteristics (Roudaut, 1998). One of the obvious characteristics of crispy foods is the generation of a shattering sound while being bitten or crushed. Crispness may be the most important sensory attribute of snack foods, and represents the critical factor that limits their shelf life. Szczesniak and Kahn (1971) used in-depth interviews with mostly open-end questions to define the crispness, and made the following statements: “Crispness is synonymous with freshness. Fresh vegetables, fruits, and snacks are though to be best when they are firm and crisp”. Crispness is commonly measured by sensory evaluation and/or by the sounds generated during biting or compressing foods.

The relationship between crispness and characteristics of crushing sounds has been studied by several researchers. Vickers and Bourne (1976) studied tape-recorded sounds from biting wet and dry crisp foods, and reported that crispness is primarily an acoustical sensation. Mohamed et al. (1982) measured the crispness of several different food products and found that the average sound energy correlated with sensory crispness. Nicholls (1995) reported that when a cellular structure is compressed, structural failure occurs via the bending and buckling of the cell walls resulting in sound emission with a rapid release of energy. Roudaut et al. (1998) described that crispy products have a low density cellular structure, and they are brittle, friable and generate a loud and high pitched sound when fractured.

Sound can be measured directly from human subjects chewing/biting the food or indirectly from foods being crushed by an instrument. Lee et al. (1988) distinguished fresh and stale potato, and tortilla chips by the frequency components of sound generated during a series of ten consecutive chews. They found that sounds from fresh samples were louder and had a greater amount of high-frequency components than those from stale samples. Dacremont (1995) recorded the sound by biting eight foods to discriminate the crunchiness and crackliness of the foods. Chakra et al. (1996) determined the parameters characterizing the emitted sound wave when force is applied to the brittle products. They observed that the energy required to bring a product to rupture is the resistance of a product to sudden crack propagation, and reported that the acoustical energy increases with increasing the mechanical energy.

The mechanical textural properties of snacks have been studied by various investigators. Texture is usually quantified by plotting the force required to deform or break samples vs. their deformation (Segnini et al. 1999). Szczesniak and Hall (1975) examined potato chips with the General Foods Texturometer, and related the first peak height from a two-bite compression cycle to crispness. Bourne (1975) illustrated the force-deformation curve for a pretzel and a corn curl compressed by 80% through a two-bite compression cycle with an Instron Universal Testing Machine, and noted that these two products have low cohesiveness and undergo brittle fracture, which are characteristics of a crisp foods.

Acoustic signals have been analyzed, through the use of the Fast Fourier Transformation (FFT) algorithm that enables conversion of the “raw” amplitude-time record into a power-frequency relationship: this allows the sound spectrum to stand out at different frequency components (Gatchalian and De Leon, 1994; Lee et al. 1988). The frequency spectrum typically has the energy per unit frequency, and must be integrated over a finite bandwidth to give the total energy in that bandwidth. The term “Power Spectra Density (PSD)” is used for this finite and constant power spectrum (Randall and Tech, 1987). The power spectrum can then be quantified and represents the crisp sound energy. It provides a meaningful interpretation of the sound signals, which is related, for example, to the crunchiness in cereals (Harris and Peleg, 1996), the detection of freeze-cracking during cryogenic freezing (McCambridge et al., 1996), the maturity of coconut from the tapping sound (Gatchalian and De Leon, 1994), and the firmness of peach (Murillo et al., 1997).

High temperature-short time extrusion cooking technology has been applied extensively in manufacturing crispy snack foods. The crispness of such products can be altered by manipulating ingredients and/or extrusion processing conditions such as screw speed, feed rate, or barrel temperature. The objective of this study was to examine the effects of ingredients and extrusion conditions on crispness of peanut-based snack products by characterizing the acoustic signals recorded in quantitative terms and the mechanical properties.

MATERIALS & METHOD

Materials

A mixture of peanut and rice flour was blended at three levels of peanut flour (30, 40, and 50%) to rice flour using a ribbon blender (Model HD1 ½ - 3SS, Munson Machinery Co., Utica, NY), and was extruded at three levels of feed rate (4, 5, and 6kg/hr) and screw speed (200, 300, and 400rpm) in a co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England). The temperature profiles of the extruder barrels was set to be 100, 120, 110, 95, and 80ºC from feed zone to die. The barrel temperatures of zone four and five was set blow 100ºC to prevent puffing of extrudates. The extrudates were cut into 2.0 ± 0.5cm^2 pieces before being dried at 50ºC and 20% RH to obtain half-products with 11-12% moisture content. Half-products were puffed by deep-fat frying at 200 ± 5ºC for 35-40sec in pure vegetable oil (The detailed procedure to produce half-products and final snack products is in Section II).

Sound Recording Apparatus

In order to prevent interference by outside noise and collect the sounds generated by compressing snack products, a ‘sound box’ was made by lining a polystyrene foam box with foam rubber ‘egg crate’ material. In the top of the box was made a hole, which was big enough to accommodate the Instron crosshead, shaft, and tool, so the sample could be compressed. A door for the insertion of snack sample was provided while a hole was made in the side to hold a microphone. A wire mesh cage was made to keep the shattered pieces of snack samples. The wire mesh cage was fitted into a shallow pan to contain pieces of sample and allow collection of the maximum amount of crispy sound. The major function of the ‘sound box’ was to allow for consolidation of the crushing sound so that the microphone could pick the sound with highest fidelity and least interference.

Acoustical Properties Measurement

The acoustical measurement was conducted by recording the sound generated by compressing peanut-based extruded snack products using the Instron Universal Testing machine (Model 5544 Instron Cop. Canton, MA) equipped with a 200kg load cell. This test consisted of crushing ("biting") the puffed snack product between parallel metal plates. The snack sample rested on the stationary lower plate while the parallel upper plate was driven downward at crosshead speed of 60mm/min. The snack sample was compressed to 95% of its original thickness in the Instron machine, and the crushing sound was imported into the computer. The wire mesh cage was placed on the lower plate to prevent losing the shattered pieces of samples. Tests were run several times without a snack sample to identify the Instron's background noise, which was later filtered out from the product's raw acoustic signature using the Matlab program.

A unidirectional condenser microphone (model 33- 3017, Optimus, Forth Worth, TX), which has a frequency response over the range 70Hz to 15kHz was connected to an analog sound recorder (model 32-1160, Optimus, Forth Worth, TX). The microphone head was place as near to the sample as possible to enable the maximum sound pick-up. To improve sound quality, the analog sound was passed through a Graphic Equalizer (model EQ EIGHT / II, Audio Source, Burlingame, CA), which had ten-band stereo with spectrum analyzer display, and was connected to the computer. The recorded crushing sound was imported into a computer equipped with a sound card (Sound Blaster Live! Value, Creative Technology, Singapore) with an analog to digital converter. In order to prevent a sound aliasing , the chosen sampling frequency must be at least twice as high as the highest frequency component in the signal: a sampling rate of 44,100Hz was selected. A 16 bits sample size was chosen to record the amplitude of the sound accurately, and two-channels of sound, which corresponded to data from two speakers, were recorded (Table 7.1).

Table 7.1. Ten-band graphic equalizer and SoundBlast digitizing parameter settings used for the digital signals of peanut-based extruded snack products

	equalizer[a]		digital recording parameters	
bass	30Hz	-12	sampling rate	44,100Hz
	60Hz	-12	resolution	16 bit
	120Hz	-12	channel	stereo
	240Hz	-12		
mid	500Hz	-9		
	1kHz	+6		
	2kHz	+9		
treble	4kHz	+12		
	8kHz	+9		
	16kHz	+6		

[a]Left and right channel of equalizer were set the same.

Mechanical Texture Analyses

A compression test was conducted to determine the texture of peanut-based extruded snack products. The mechanical texture properties of the snack products were derived from the force-deformation curve generated by compressing snack products using the Instron Universal Testing machine (Model 5544 Instron Cop., Canton, MA). A 200kg load cell was used to compress the snack products up to 95% of their original height. The Instron crosshead speed was 60mm/min. The first deformation peak force and the mechanical energy were measured: the energy, work at structure failure, represents the area under the force-deformation curve from the time the upper plate contacted the food to the deformation at which the first peak force occurred. The energy was calculated dividing the sample weights by the value of area, which was obtained by integrating the area under the force-deformation curve at the first peak.

Acoustical Data Analysis

The sound file analysis was carried out using the Matlab® (The Math Works Inc., Natick, MA) program for a numerical integration. The background noise signal was filtered out from the sampled signal. A Fast Fourier Transformation (FFT) algorithm transforms the vector that contains the signal by converting data in the time domain into a frequency domain. A radix-2 fast Fourier transform algorithm was applied. For this algorithm, the length of data sequence should be a power of two. If the number of data points to be transformed is not a power of two, the program pads the remaining data with zeros (Randall and Tech, 1987). The acoustic sounds were sampled at a frequency of 44,100Hz sampling rate, and 524,288 data points, corresponding to the 11 seconds average duration of sound recording, were captured from the digitized data.

RESULTS & DISCUSSION

Acoustical Analyses

Sound signals produced by crushing crisp foods are typically non-stationary and irregular. The sound signals of crispy food products and their frequency composition are an irregular series where spectral characteristics change over time (Liu et al., 1999). Fig 7.1 shows the sound spectrum in time domain generated during compression of snack products extruded with three different ratios of peanut flour (30, 40, and 50%) at feed rate of 6kg/hr. It was clear that the snack product containing 30% peanut flour (Fig 7.1-a) produced a high acoustic emission, whereas the acoustic emission produced by snack products containing 40% and 50% peanut flour (Fig 7.1-c) was reduced considerably. This can be interpreted that the crispness of snack products increased with decreasing level of peanut flour. Liu et al. (1999) reported that in the time-amplitude spectrum, the higher amplitude snack foods can be described as crisper than others. Vickers (1987) also reported that crispness is positively related to the number of sound occurrences and the amplitude of these sounds.

Historically, the Fourier transform has been extensively used to characterize the noise emitted by selected crispy foods (Seymour and Hamann, 1988; Lee et al., 1988; Rohde et al., 1993). Fast Fourier transformation (FFT) was designed to process stationary signals, i.e., signals where the spectral characteristics are time independent (Randall and Tech, 1987), and to transform the sound signals into a power spectrum to identify characteristic frequencies of the foods. For stationary acoustic signals, frequency spectrum typically has the units of energy per unit frequency, and must be integrated over a finite bandwidth

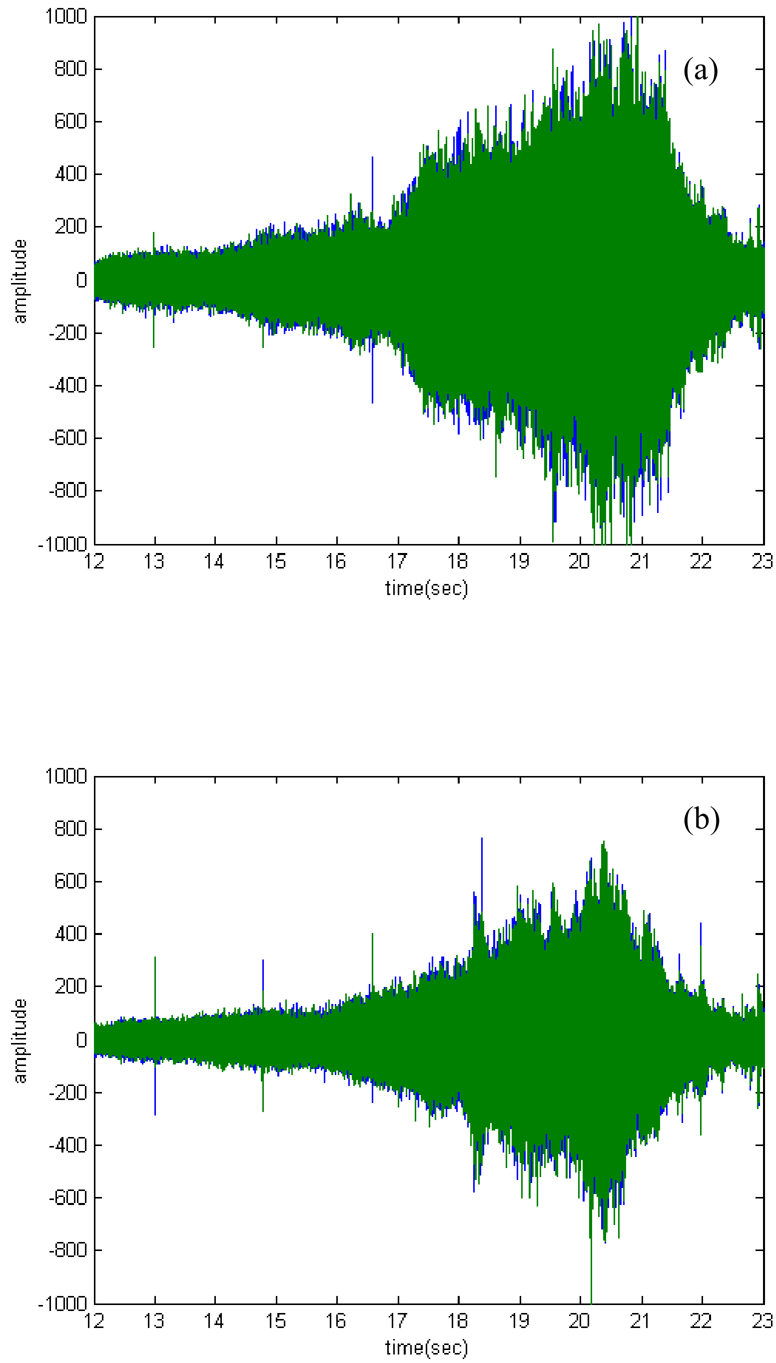


Fig 7.1. Sound spectrum generated during compression of the peanut-based snack products extruded with (a) 30% peanut flour and (b) 40% peanut flour at feed rate of 6kg/hr

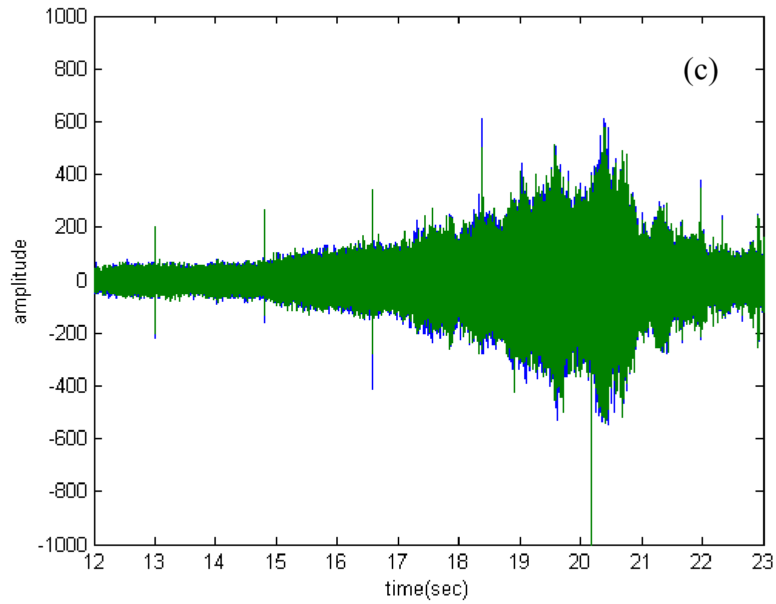


Fig 7.1. Sound spectrum generated during compression of the peanut-based snack product extruded with (c) 50% peanut flour at feed rate of 6kg/hr

to give total energy for that bandwidth. In particular, the power content of each frequency has the dimensions of "spectral density", and for this finite and constant frequency spectrum, the term "Power Spectra Density (PSD)" is used. Power spectra density (PSD) is often the most useful part of the signal analysis, and the energy of crisp sound is related to the area under the frequency-amplitude curve of PSD (Randall, 1987).

The acoustical signal of peanut-based extruded snack products was characterized by its frequency and its energy (Fig 7.2). Fig 7.2 represents the power spectra density of the three sound signals shown in Fig 7.1. The background noise recorded without sample contained low amplitude noise, and was filtered out before the frequency components of snack products were identified. The predominant frequency ranges that the snack products generated during compression extended between 4.5-8.5kHz and all the information characterizing the signals was located between 3.0kHz and 13.0kHz. Any frequency components higher than 13.0kHz would be of no significance (Lee et al. 1988: Chakra et al. 1996). The PSDs were complex and exhibited multiple regions of high and low amplitude sound. The 30% peanut product had the most complex pattern with high intensity regions peaking at about 5.0, 5.5, 6.5, 8.0, and a broad region from 9.0 to 12.0 kHz. The 40% peanut product had peak amplitude regions at about 6.0, 8.5, and 10.0 kHz, and the 50% peanut product had a similar pattern with peaks at 6.2, 7.8, and 10.0 kHz. There was a typical breaking pattern shown in the power spectrum in Fig 2 characterized by high-intensity spikes. Such spikes showing relatively high amplitude occurred at around 6.5kHz and 10.0kHz for 40 and 50% peanut products, while the 30% product exhibited many high-intensity spikes over a range of frequencies. Lee et al.

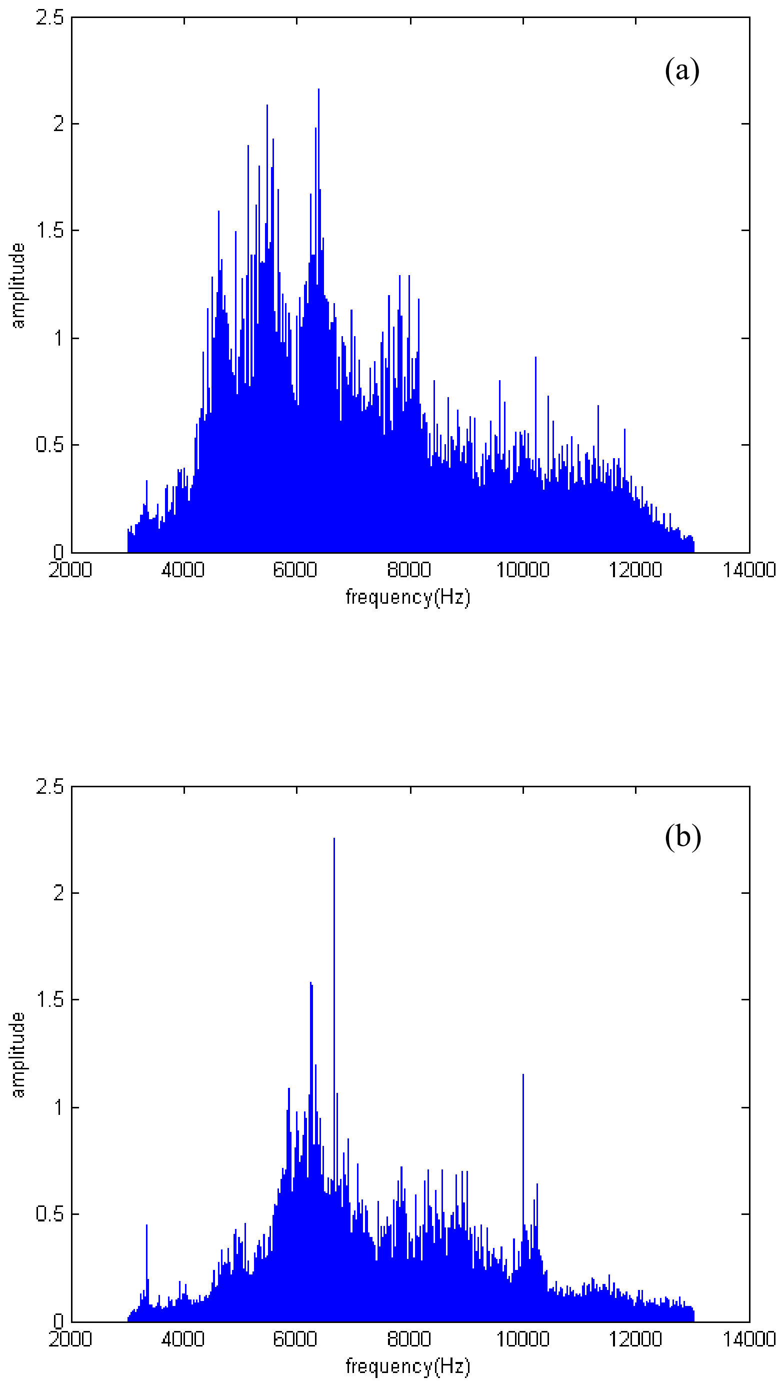


Fig 7.2. Power Spectra Density (PSD) of peanut-based snack products extruded with (a) 30% peanut flour and (b) 40% peanut flour at feed rate of 6kg/hr

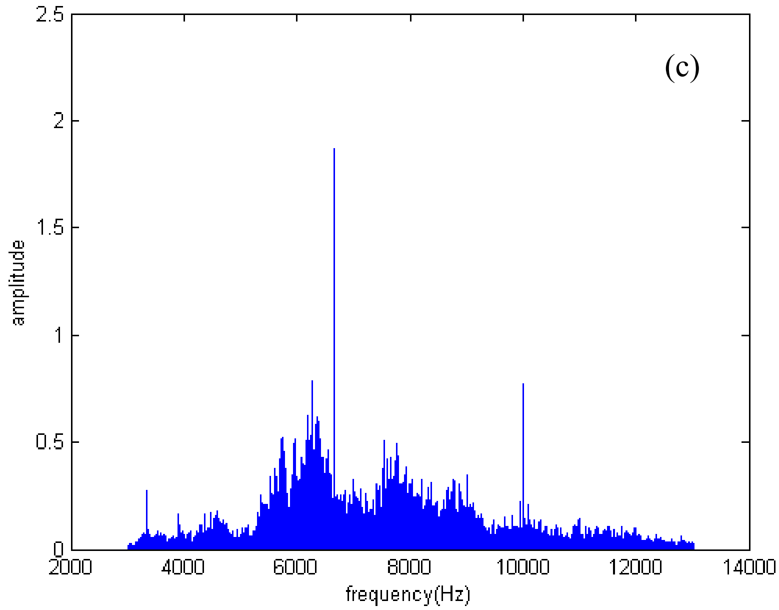


Fig 7.2. Power Spectra Density (PSD) of peanut-based snack products extruded with (c) 50% peanut flour at feed rate of 6kg/hr

(1988) analyzed the frequency components of sound generated during ten consecutive chews, and reported that evaluation showed a “double hump” spectrum associated with the first chew, the first hump maximum at 3.0-4.0kHz and the second hump at about 6.0kHz. The tortilla chip spectra also showed a “double hump” behavior with louder sound during the initial chew that was less difference for later chew. Tesch et al. (1996) recorded the acoustical emissions of cheese balls and croutons. The acoustical signatures were transformed into power spectrum to identify characteristic frequencies, and they reported that the power spectrum of the acoustic signature indicates peak emission at about 10.0kHz.

The amplitude (sound intensity) of the signal at each frequency component is one of the most used parameter for characterizing a given signal. The amplitude increased with decreasing the level of peanut flour. Fig 7.2 shows that for 30% peanut product, the highest intensities within the various regions were approximately 1.5 at 5.0 kHz, 2.25 at 5.5 and 6.5 kHz, 1.3 at 8.0 kHz, and 0.9 within the 9.0-12.0 kHz regions. For 40% peanut product the intensities were 1.6 at 6.0 kHz, 0.7 at 8.5 kHz, and 1.2 at 10.0 kHz. For 50% peanut product, the values were 0.6 at 6.2 kHz (but also strong signal at 6.5 kHz representing initial fracture of the curved product), 0.5 at 7.8 kHz, and 0.7 at 10.0 kHz.

Energy of the acoustical signal has a great importance in the characterization of the sound as it is directly linked to the physical structure: the energy is equal to the area under the frequency-amplitude curve of power spectra density (PSD). When feed rate was 6kg/hr, the area value under the PSD increased with decreasing the level of peanut flour (Table 7.2). It can be explained that the snack products containing less peanut flour produced more crispy sound compared to that high peanut flour. The area under the PSD

Table 7.2. Area under the Power Spectra Density (PSD)

Formulation		
PF (%)	FR (kg/hr)	area
30	4	443.8356
	5	724.4165
	6	1034.40
40	4	561.9214
	5	715.2820
	6	542.4365
50	4	439.3487
	5	347.9664
	6	281.8402

PF = peanut flour (%)
FR = feed rate (kg/hr)

of snack products extruded with the peanut flour of 30% was from 443.84 to 1034.40, whereas for those containing 40% and 50% peanut flour, from 542.44 to 715.28 and from 281.84 to 439.35, respectively.

Chakra et al. (1996) studied the sound emission during rupture of a brittle product, and defined the acoustical energy. They reported that when all brittle objects were subjected to a mechanical force, the mechanical energy during deformation could be stored in the form of elastic potential energy. As the applied stress reaches a critical value, rupture induces an instantaneous liberation of the partially transformed energy in the form of acoustical energy. Mohamed et al. (1982) measured the crispness of several different food products and found that the average sound energy correlated with their crispness. Vickers and Bourne (1976) also proposed the theory of the sound produced by biting crisp foods by analyzing the frequency spectra and its amplitude. They reported that the ability of a crisp food to produce sounds on biting or crushing was due to its physical properties, especially the cellular structure of the products.

Characteristics of peanut-based snack products were studied in previous sections of cell size distribution analyzed by Scanning Electron Microscopy (SEM) and sensory evaluation. The SEM showed that the snack products extruded with high level of peanut flour (50%) had small cell size with thicker cell walls compared to those low levels of peanut flour (30%). In addition, the results of descriptive sensory analysis indicated that the low peanut flour products were crisper and less hard than those high peanut flour products. Moreover, from the consumer-based optimization, the optimum area of formulation and extrusion processing conditions that could be acceptable to consumer was peanut flour of 30-42% and feed rate of 4-6kg/hr. The acoustical analysis also indicated that the low peanut flour product produced a high acoustic emission, showed high amplitude in the major peak frequency ranges, and generated more acoustical energy.

Mechanical Texture Analyses

Fig 7.3 shows a typical force-deformation curve of a compression test of peanut-based snack product. There was a general breaking pattern for the snack products. The force-deformation curve represented roughly three basic stages. The first stage, A, was extended up to breaking into two or three pieces. The puffed snack product, due to its curvature, was broken into several pieces at the time the upper plate contacted the snack sample to begin deformation. In stage A, an increase in force was found at the initial breaking of the snack sample into several pieces. After the initial breaking, the compression force decreased sharply. The second stage, B, was the further crushing of the pieces of snack product broken in the first stage. The broken pieces of snack product were compressed further in the stage B where the snack product exhibited substantial deformations with several peaks prior to the complete crushing. There were the collapse of the cellular structure and densification of the broken snack products in the second stage. Deformation in stage B was longer than stage A, and the force increased as the deformation was close to the stage C. The final stage, C, at which the force steeply increased as the snack sample was compressed up to 95% of its original height, was the continuation of the force-deformation curve immediately after the second stage.

The determination of mechanical properties may be one of the most prevalent objective measurements for crispness. Mechanical properties are believed to reveal the

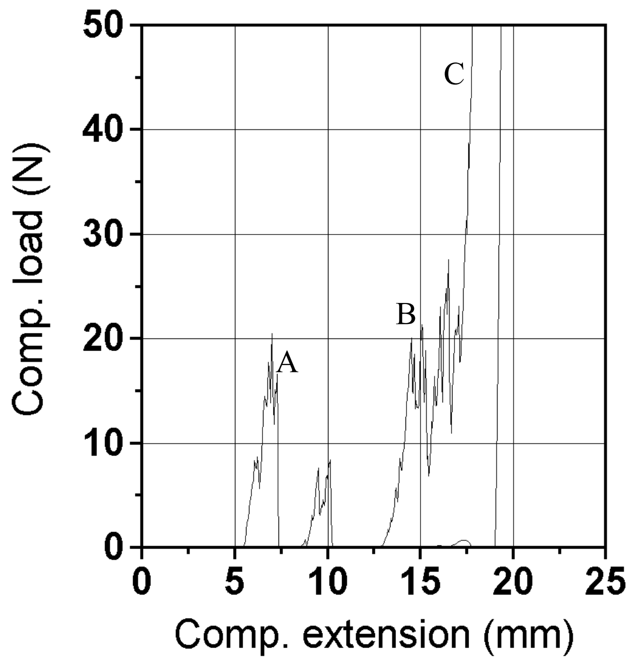


Fig 7.3. Typical force-deformation curve of compression test of peanut-based extruded snack product

structural properties of materials by means of the resistance to a compression of blade/probe and to a tensile force that pulls apart the structure of food material (Bourne, 1982).

The peak force (N) and energy (mJ/g) at the first peak were used as the indicators of crispness of peanut-based extruded snack products. Fig 7.4 shows three force-deformation curves obtained on compression of snack products extruded with three different ratios of peanut flour (30, 40, and 50%) at feed rate of 4kg/hr showing the force at first peak. These curves also show that the breaking pattern relatively varied to depending on the level of peanut flour. The breaking force of low level of peanut flour (30%) at the first peak was lower than that high level of peanut flour (50%) product. The force-deformation curves indicated that generally, the first deformation peak force increased with increasing the amount of peanut flour.

The effect of the level of peanut flour (%) varying between 30% and 50% with three feed rates (4, 5, and 6kg/hr) on the first peak force and the energy are shown in Fig 7.5. The first deformation peak force (N) ranged from 19.89 to 32.79. The highest value of 32.79 was given to the product extruded with peanut flour of 50% at feed rate of 4kg/hr, whereas the lowest force of 19.89 was given to the product extruded with peanut flour of 30% at feed rate of 6kg/hr. The first peak force was affected only slightly by feed rates for 30 and 40% peanut flour product, but exhibited more variation for 50% peanut flour. The first peak force value showed that the products extruded with low peanut flour was mechanically weaker than those high peanut flour products, and could be explained that these products might be crisper than the others. It could be explained that the high

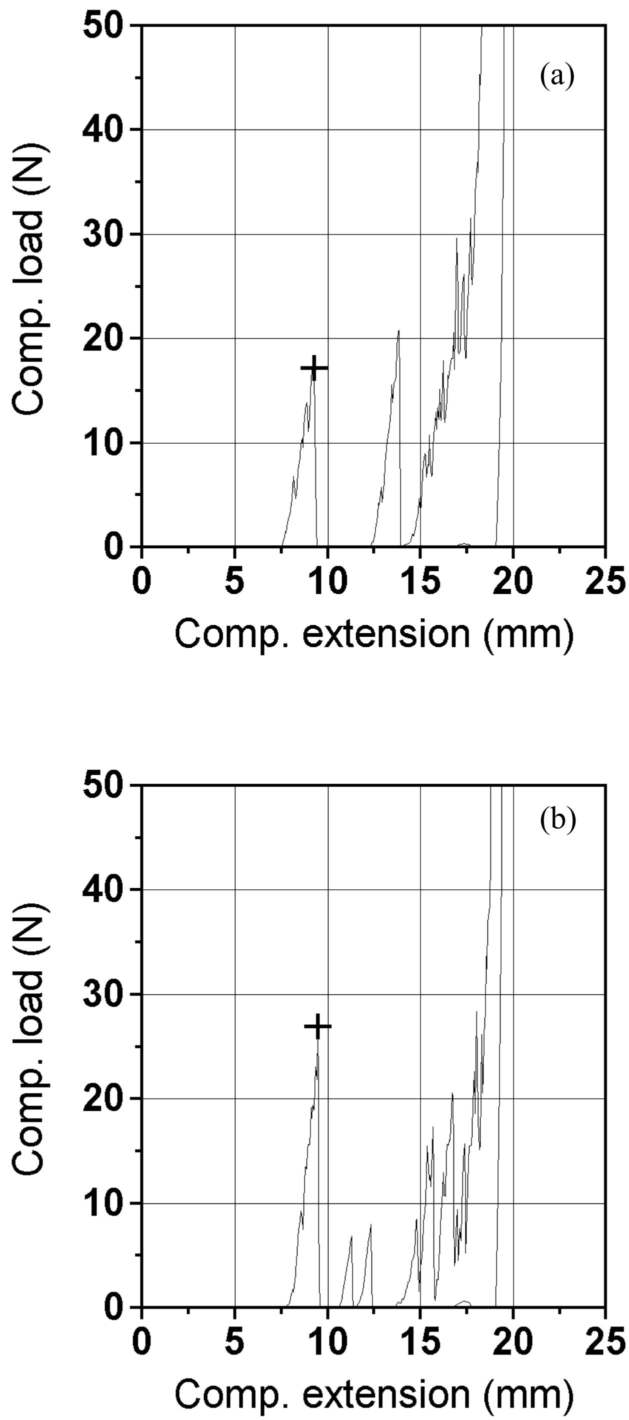


Fig 7.4. Force-deformation curves of compression test of snack products extruded with (a) 30% peanut flour and (b) 40% peanut flour at feed rate of 4kg/hr

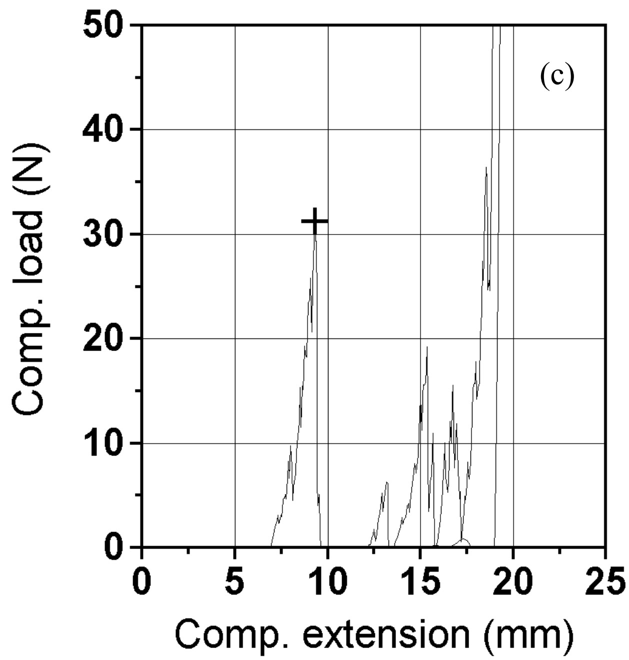
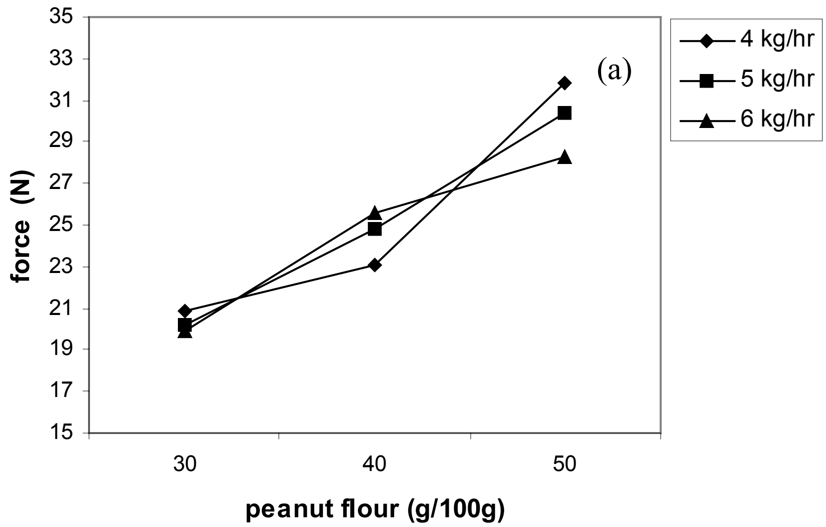


Fig 7.4. Force-deformation curve of compression test of snack product extruded with (c) 50% peanut flour at feed rate of 4kg/hr



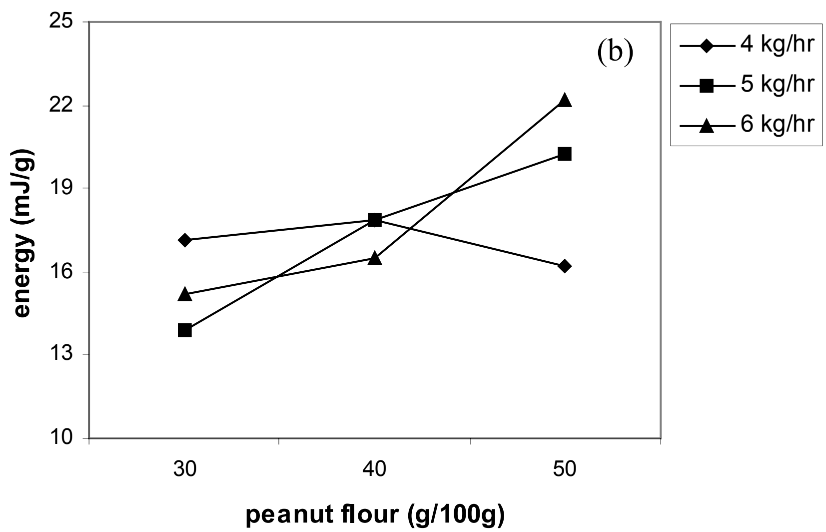


Fig 7.5. Effects of the level of peanut flour (%) and feed rate (kg/hr) on the (a) first-deformation peak force (N), and (b) mechanical energy (mJ/g) at the first peak

protein and fat component in the high peanut flour mixture interfere the plasticization of starch resulted in low expansion and high bulk density of product.

Sherman and Deghaidy (1978) examined Instron maximum force for low moisture foods, and reported that the more brittle the food, the lower the force required to rupture it. Vickers (1987) reported that since the force measured by biting the crisp food products may indicate hardness or toughness, the peak force is negatively related to crispness. Vickers (1988) also measured crispness by combinations of acoustical and force-deformation curves, and reported that crispness is positively related to acoustical measurement of compressive brittleness and inversely related to force-deformation measurements. Seymour and Hamann (1988) extracted the mechanical variables from a force-deformation curve: the maximum peak force was used to determine hardness and brittleness, and the area under the peak force was used to determine the energy required compressing or biting the products. Szczesniak and Hall (1975) investigated the crispness of potato chips with the General Foods Texturometer, and related the first peak height from a two-bite compression cycle to crispness.

The mechanical energy (mJ/g), area under the first peak of the compression test is the work required for structural failure at the moment the stress applied to the snack product. The mechanical energy decreased with decreasing the level of peanut flour, which means that the work for structural failure was low for the 30% peanut flour snacks compared to the 50% products. The Energy at the first peak ranged for 30% peanut flour product from 15.19 to 17.12, for 40% peanut flour product from 16.49 to 17.85, and for 50% peanut flour product from 16.21 to 22.22. The lowest value of 13.93 was given to the product extruded with peanut flour of 30% at feed rate of 5kg/hr showed the lowest value of

13.93. Whereas the highest value of 22.22 was given to the snack product extruded with peanut flour of 50% at feed rate of 6kg/hr.

The previous study of physical properties of peanut-based extruded snack products indicated that the low levels of peanut flour snacks were expanded more than those high levels of peanut flour. It can be explained that low peanut flour product has more large air cells and that one might expect that bigger air cell products might be weaker than high peanut flour products with smaller cells and denser structure. This information might be used as an indicator of crispness intensity. Stanley (1986) reported a similar result that force-deformation curves were related to microstructure in that porosity of the extrudate influenced the number of peaks recorded before the sample failed: highly porous samples had more than twice the number of peaks of less porous extrudate.

Most brittle, crispy foods can be characterized by the jaggedness of their force-deformation curves. Rohde et al. (1993) reported that what is known as "crispness" is indeed associated with the jaggedness of the force-deformation curve, and consequently with the mean magnitude of the spectrum. Norton et al. (1998) examined the multi-peak curves obtained on compression of expanded extruded rice with a range of water contents. They demonstrated crispy product had more jagged lines with low compression force, and also reported that negative correlation of maximum force with crispness, which was agreed with Seymour and Hamann (1988). Seymour and Hamann (1988) investigated the crispness and crunchiness of five low moisture foods subjected to three humidity conditions. They reported that the primary indicators of crispness and crunchiness are the mechanical force and work required to fracture the sample, and acoustical variables play an important supporting role.

Relationship between Acoustical/Mechanical Properties and Sensory Evaluation

Relationship between Acoustic/Mechanical Properties and Consumer Acceptance Test: Table 7.3 shows the relationship between acoustical/mechanical properties and the attributes of consumer acceptance test. The acoustical energy from power spectra density (PSD) affected significantly to the crispness and texture. Mechanical force was found to be important to the overall liking, crispness, and texture, whereas mechanical energy was important to the crispness.

Relationship between Acoustic/Mechanical Properties and Descriptive Analysis: acoustical energy had a relationship with the hardness, crispness, persistence of crunchiness, and persistence of fracturability (Table 7.4). The mechanical force was found to be important to crispness, fracturability, persistence of crunchiness, and persistence of fracturability. On the other hand, mechanical energy had a relationship with roughness and crunchiness.

Relationship between Acoustic/Mechanical Properties and Physical Properties: Table 7.5 shows the relationship between acoustical and mechanical properties and physical properties. Physical properties of thickness of half-products, bulk density, and volume expansion ratio affected to acoustical energy significantly. All physical properties were found to affect to the mechanical force except volume expansion ratio. No relationship was found between physical properties and mechanical energy.

Relationship between Acoustic/Mechanical Properties and Cellular Structure: Cellular structure parameters of average cell size and the number of cells had a significant relationship with the acoustical energy, mechanical force, and mechanical energy (Table 7.6).

Table 7.3. Significant correlations between the attributes of consumer acceptance test and acoustical/mechanical properties of peanut-based extruded snack products

attributes	acoustical and mechanical parameters		
	acoustical energy	mechanical force (N)	mechanical energy (mJ/g)
overall liking	ns	-6.33*	ns
crispness	-0.062***	0.729***	0.001***
texture	-0.089***	1.014***	ns

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Table 7.4. Significant correlations between the descriptive attributes and acoustical/mechanical properties of peanut-based extruded snack products

descriptive attributes	acoustical and mechanical parameters: acoustical energy	mechanical force (N)	mechanical energy (mJ/g)
Texture			
Roughness	ns	ns	0.008*
Hardness	0.488***	ns	ns
Crispness	0.546***	-0.417***	ns
Crunchiness	ns	ns	0.003**
Fracturability	ns	0.274**	ns
Persistence of Crunchiness	0.164***	0.504***	ns
Persistence of Fracturability	0.143***	0.375***	ns

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Table 7.5. Significant correlations between the cellular structure and physical properties of peanut-based extruded snack products

physical properties	acoustical/mechanical parameters		
	acoustical energy	mechanical force (N)	mechanical energy (mJ/g)
degree of gelatinization	ns	0.486*	ns
thickness of half-products	0.0001**	-0.005***	ns
bulk density	-0.0001***	0.004**	ns
volume expansion ratio	0.006**	ns	ns

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$
*significant at $p \leq 0.1$

Table 7.6. Significant correlations between cellular structure and acoustical/mechanical properties of peanut-based extruded snack products

cellular structure parameters	acoustical and mechanical parameters		
	acoustical energy	mechanical force (N)	mechanical energy (mJ/g)
average cell size	0.007**	-0.314***	0.118***
number of cells	-0.069***	1.635***	-0.442***

***significant at $p \leq 0.01$
**significant at $p \leq 0.05$

CONCLUSIONS

Acoustical and mechanical texture properties were determined from acoustical signals and force-deformation curves generated during compression of peanut-based extruded snack products, respectively. As the level of peanut flour increased, there was a decrease

in the acoustical emission, and an increase in the mechanical parameters of first deformation force and work for structure failure. The overall sound emission of the 30% peanut flour snack product was greater than the 50% peanut flour snack product. Mechanically, snack product extruded with 30% peanut flour was weaker than those extruded with 50% peanut flour. Crispness of peanut-based snack products could be explained relatively well by combining acoustical and mechanical properties. All three types of snack products extruded with different ratios of peanut flour may be characterized by being influenced by frequencies around 4.5-8.5kHz including the multiple peak frequency ranges. The power spectra density (PSD) indicated that the amplitude and energy of acoustical signals dropped with increasing the level of peanut flour. The corresponding force-deformation curve showed that the mechanical parameters of first deformation force and energy increased with increasing the level of peanut flour.

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SECTION VIII

SUMMARY AND CONCLUSIONS

Extrusion processing has become the standard operating system in most snack food industries. The main advantages of extrusion cooking is its energy efficiency, the lack of process effluents, and its versatility with respect to ingredient selection and the shapes and textures of products that can be produced. The evolution of snack foods has been described with certain types of snacks being associated with a specific generation of products. Third generation snack are indirect expanded snacks by extrusion processing followed by additional puffing steps by deep-fat frying or hot air stream to achieve the final texture. Several different raw materials may be used in a formulation suitable for third-generation snacks. Peanuts are probably the most versatile food ingredient, also a good source of protein and amino acids, and can be used to supplement starch-based snacks to improve the nutritional quality. Rice is one of the largest crops grown in the world and the use of rice as a food ingredient keeps expanding with its functional benefits. Typically rice flour is about 75-80% starch, and depending on the type of starch rice flour can be used to improve the texture: blending rice flour increases the crispness and expansion in fried or baked snack chips.

The development of the half-product and its final snack type foods was the main purpose of research. The extrudates were produced with mixture of partially defatted peanut flour (12% fat) and rice flour using a co-rotating twin-screw extruder. The extrudates were dried to obtain half-products with 11-12% moisture contents, and the half-products were expanded by deep-fat frying at 200ºC for 35-40 sec. Peanut flour (30, 40, and 50%), screw speed (200, 300, and 400rpm), and feed rate (4, 5, and 6kg/hr) were the factors influencing the half-products, which subsequently affected the quality of final puffed snack products. The physical properties, cellular structure, acoustical signal analysis, and sensory evaluation were conducted to determine the quality of peanut-based extruded snack products. Response Surface Methodology (RSM) was used to predict the optimum area of formulation and extrusion processing conditions to produce the snack products that would be acceptable to consumer.

The effects of formulation and extrusion conditions were examined by measuring the physical properties of snack products. The amount of peanut flour was the most responsible for the quality of the half-products and their final puffed products, followed by feed rate and screw speed, respectively. The Optimum area for formulations and extrusion processing conditions were determined using Response Surface Methodology (RSM). The optimum area was identified at a peanut flour of 30-38% and feed rate of 4.0-5.2kg/hr.

The cell structure of snack products was investigated by using a Scanning Electron Microscopy (SEM). Snack products were distinguishable by their internal structure. The average cell size and cell density predominantly determined the geometric differences varying to the level of peanut flour, screw speed, and feed rate. Increasing peanut flour resulted in less expanded snack products with smaller cell size resulting in an increase in the number of cells. The product extruded at medium level of screw speed (300rpm) produced larger cells, and consequently decreased the cell density.

Acoustic and mechanical properties were characterized to determine the effects of peanut flour and feed rate. The frequencies and acoustical energy were identified and quantified by a Fast Fourier Transformation (FFT) algorithm. The peak frequencies ranged from 5.5kHs to 6.5kHz corresponding to varied intensity, and the power spectra density (PSD) indicated that the 30% peanut flour snack product produced three times more acoustical energy than those 50% peanut flour. The force-deformation curve of mechanical measurement indicated that the deformation force and the mechanical energy at the first peak decreased with decreasing the level of peanut flour: 30% peanut flour snack product was mechanically weaker than 50% peanut flour.

The peanut-based extruded snack products were evaluated among the target population to determine if they were of acceptable sensory quality. A consumer acceptance test was conducted to measure overall liking of the peanut-based extruded snack products, and Quantitative Descriptive Analysis (QDA) was conducted to characterize the overall sensory profiles. A consumer-based optimization was performed to determine the optimum formulations and extrusion processing conditions to produce the snack products acceptable to consumers using Response Surface Methodology (RSM). It was identified that the optimum area was bounded by a smooth curve encompassing an area beginning at a peanut flour (PF) of 39% and feed rate (FR) of 4.0kg/hr, rising to a maximum at 42.5% PF and 4.6kg/hr FR, and decreasing to 31.5% PF and 6.0kg/hr. Descriptive analysis indicated that the most characteristics of sensory attributes were brown color, roughness, porosity, and puffiness for appearance, roasted peanutty and bitter for aromatics and taste, and roughness, hardness, crispness, crunchiness, and fracturability for texture.

In conclusion, indirectly expanded snack product made from different ratios of peanut flour to rice flour could be successfully extruded using a twin-screw extruder, and puffed by deep-fat frying. The physical properties of the extruded pellets and their expanded snack products were investigated. The low peanut flour (30-40%) puffed snack products were acceptable to consumers.

APPENDIX

DEMOGRAPHIC QUESTIONNAIRE

Panelist Code: _______ Date: __________

Please answer all questions. Your name is not on the questionnaire. All information is confidential and will not be identified with your name.

1. What is your age group? (Please check ONE)
   18-24 years old _____ 25-34 years old _____ 35-44 years old _____
   45-54 years old _____ 55-64 years old _____ over 64 years old ____

2. What is your gender? (Please check ONE)
   Male _____ Female _____

3. Which do you consider yourself to be? (Please check ONE)
   White _____ Black _____ Spanish/Hispanic _____
   Asian _____ Other (please specify) _____

4. What is your marital status? (Please check ONE)
   Never married _____ Married _____ Separated/Divorced _____ Widowed _____

5. Level of education (Please check the ONE which best applies to you)
   _____ Less than 8 years of school
   _____ 9-12 years of school
   _____ Graduated high school or equivalent
   _____ Some college or vocational school (< 4 yrs)
   _____ Completed college (B.S.)
   _____ Graduate or professional school (masters, Ph.D., law, medicine, etc.)

6. Please check the ONE which best applies to you:
   _____ Employed full-time _____ Student
   _____ Employed part-time _____ Unemployed
   _____ Homemaker _____ Retired

7. What was the approximate level of your household income before taxes last year? (Please check ONE)
   _____ Under $10,000 _____ $40,000 to $49,999
   _____ $10,000 to $19,999 _____ $50,000 to $59,999
   _____ $20,000 to $29,999 _____ $60,000 to $ 69,999
   _____ $30,000 to $39,999 _____ $70,000 and over

Panelist Code: _______ Sample Code: _______ Date: __________

SCORE SHEET

Please evaluate sample _________ and answer the following questions. Put a check on the space that best reflects your feeling about this sample.

1. How do you like the "APPEARANCE" of this product?

dislike extremely extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

2. How do you like the "FLAVOR" of this product?

dislike extremely extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

3. How do you like the "CRISPNESS" of this product?

dislike extremely extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

4. How do you like the "TEXTURE" of this product?

dislike extremely extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

5. Overall, how do you "LIKE" this product?

dislike extremely extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

6. Is this product ACCEPTABLE? Yes [ ] No [ ]

Thank you very much

CONSENT FORM

I, ___________________________, agree to participate in the research entitled "Consumer-based optimization of an extruded snack product using Response Surface Methodology (RSM)" which is being conducted by R. D. Phillips and A. V. A. Resurreccion of the Department of Food Science and Technology of the University of Georgia, phone number (770) 412-4744.

I understand that participation is entirely voluntary. I can withdraw my consent at any time and have the results of the participation returned to me, removed from the experimental records, or destroyed.

The following points have been explained to me:

1. The reason for the research is to gather sensory information on consumer opinions of food samples and the benefits that I may expect from the research are a satisfaction that I have contributed to the solution and evaluation of problems relating to such examinations.

2. This research study will be conducted from October 10 to October 11, 2001. The test will last approximately 1 hour per session. I will participate no more than 3 sessions per study. The evaluation procedures are as follows:
   Coded samples and score sheets will be placed in front of me. I will evaluate food samples by tasting, swallowing, and rinsing, and indicate my evaluation on score sheets. All procedures are standard methods as published by the American Society for Testing and Materials.

3. No discomforts or stresses are foreseen.

4. Participants entail the following risk: The risk that can be envisioned is that of an allergy to peanut based fried snack. However, because the snacks to be tested is known beforehand, the situation can normally be avoided. In the event of an allergic reaction unknown to the participants, medical treatment is available from the Spalding County Regional Hospital.

5. It is my responsibility to make known to the investigators any allergies I may have toward peanut based fried snack when they occur. I know or believe I am allergic to the following foods:___________________________

6. The results of this participation will be confidential and will not be released in any individually identifiable form without my prior written consent unless required by law.

7. The investigator will answer any further questions about the research, either now or during the course of the project.

My signature below indicates that the researchers have answered all of my questions to my satisfaction and that consent to volunteer for this study. I have given a copy of this form.

_______________________________ Signature of Investigator

_______________________________ Signature of Participant

Date: ___________________________

Witness:

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

Research at The University of Georgia which involves human participants is carried out under the oversight of the Institutional Review Board. Questions or problems regarding these activities should be addressed to Dr. Julia Alexander, Coordinator, Human Subjects Research, Institutional Review Board, Office of Vice President for Research, The University of Georgia, 606A Graduate Studies Research Center, Athens, Georgia 30602, (706) 542-6514.
