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CHARACTERISTICS OF LEGUME SUPPLEMENTED PASTA
PREPARED BY CONVENTIONAL AND MICROWAVE COOKING

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CHARACTERISTICS OF LEGUME SUPPLEMENTED PASTA PREPARED BY CONVENTIONAL AND MICROWAVE COOKING

By

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ABSTRACT

CHARACTERISTICS OF LEGUME SUPPLEMENTED PASTA PREPARED BY CONVENTIONAL AND MICROWAVE COOKING

by

Chai-Hung Lin

Pasta formulations incorporating durum wheat semolina with drum-dried bean meal (DDBM) or raw whole bean meal (RWBM) were processed through a high temperature twin-screw extrusion cooker. The cooking quality of precooked and dried pasta were evaluated following conventional (100°C, 2 mins) and microwave (740 Watts, 5 mins) cooking regimes.

Dietary fiber content and proximate composition were analyzed for raw ingredients (moisture, 11-13%; protein, 16-25%; fat, 0.8-1.6% and ash, 0.8-1.7%) and final pasta (moisture, 8-10%; protein, 16-19%; fat, 0.2-0.3% and ash, 0.6-1.3%). Extruded bean meal formulated dry pasta resulted in high protein digestibility. Microwave cooked legume pasta had higher cooked weight and was less firm than 100% semolina control pasta. Microwave preparation resulted in lower cooking loss than the conventional protocol. Sensory properties of the pasta were described using the Qualitative Descriptive Analysis. Results indicated that pasta formulated with legume ingredients were suitable for rapid preparation using either microwave or conventional cooking.

After three months accelerated storage, pasta heated by conventional and microwave energy decreased cooked weight and increased firmness with increasing storage temperature.

To my parents

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Introduction

Michigan is the leader in production of dry edible beans and accounts for nearly one-third of U.S. production annually. In Michigan, navy beans are one of the most important cash crops and amounts to about 68% of total navy bean crop in the United States.

Per capita consumption of dry edible beans in the United States has declined from about 8.4 pounds in 1940 to 6.0 pounds in 1990 (USDA, 1991). Processing, marketing and promotional strategies have been considered to increase bean consumption. In recent years, dry edible beans have been promoted for their high dietary fiber content which may serve as an aid to improve healthy diets. In addition, beans are considered one of the most suitable sources of high protein materials to complement the amino acid deficiencies of cereals.

Several researchers have sought innovative alternatives to increase bean product versatility and to increase overall dry bean utilization. Fortified pasta prepared with various dry bean flours to enhance the nutritional properties have been studied (Breen, 1977; Lorenz, 1979; Bahnassey, 1986; and Duszkiewicz-reinhard, 1988). However, some undesirable factors limiting the consumption of beans include: 1) antinutritional factors, 2) low digestibility, 3) bean flavor and 4) consuming preparation time. A drum-dried bean flour process designed to eliminate some of these undesirable factors and provide a precooked ingredient which is suitable for food formulation was developed (Occeña and Uebersax, 1992).

Pasta, in the form of flat noodles, elbow macaroni or spaghetti, is consumed worldwide. In Italy, pasta has long been used as a "staple food", while in the rest of the world, pasta has undergone a significant increase in popular consumption (Pagani, 1985). Per capita consumption of pasta products in the United States increased gradually from 7.7 pounds in 1970 to 13.1 pounds in 1990 (USDA, 1991).

Traditional pasta is prepared by a single-screw, deep flight extruder at a comparatively low temperature (about 50^{o}C). During consumer preparation of pasta, the dry product must be cooked for 10 to 15 minutes to rehydrate and gelatinize the starch. Recently, a new process utilizing a twin-screw extruder to produce pre-gelatinized short pasta products was developed (Wenger and Huber, 1988). This product possesses decreased wall thickness for rapid rehydration and the new technology can be easily applied for cooking pasta by using a microwave oven to produce a cooked pasta with moderately firm ("al dente") texture.

Microwave heating uses an electromagnetic energy which can generate heat by molecular friction among ions, water molecules or other charged particles in foods (Decareau, 1985). Using microwave energy (2450 Mhz for home use and 915 Mhz for industrial purposes) for processing or cooking foods has greatly increased in recent years. Therefore, it becomes a great challenge to produce high quality microwavable high nutrient foods. However, pre-gelatinized pasta can reduce cooking time, enhance nutrient retention, and improve convenience and ease of preparation.

The objectives of this study were: 1) to analyze the physical and chemical properties of precooked (instant) pasta formulated with semolina flour and drum-dried navy bean meal or whole raw navy bean meal followed by conventional and microwave cooking; 2) to evaluate the storage cooking quality of dry pasta stored under three different temperatures (13°C, 21°C and 40°C) with three relative humidities (56% RH, 75% RH and 86% RH) for three months.

REVIEW OF LITERATURE

LEGUMES AS A FOOD RESOURCE

Legumes in the Human Diet

Edible food legumes are valuable sources of protein and calories as well as certain vitamins and minerals important for use in human diets. They include the species of the Leguminosae that are used directly as human food as distinct from oil-bearing legumes and pasture or forage legumes. In North America, *Phaseolus* is represented by numerous common commercial classes, whereas in the Far East and Africa, the Indian genuses of *Phaseolus*, *Dolichos*, *Vigna* and *Cajans* are more important.

World production of legumes is estimated to have reached close to 60 million tons in 1990, with the developing countries producing the largest part of the total world production (FAO, 1990 and Uebersax and Occeña, 1991). Many of the developing countries (India, Brazil, Cuba and Mexico) also were responsible for a relatively large share of the demand for food legumes. However, food legumes in industrially developed countries remain relatively low in per capita consumption. For example, in the United States the per capita consumption of dry edible beans was 6.0 lb in 1990 (USDA, 1991).

Composition of Legumes

Carbohydrates

In each parenchyma cell of legume seeds, starch granules are embedded within a protein matrix (Powrie et al., 1960; Sefa-Dedeh and Staley, 1979 and McEwen et al., 1974). The total carbohydrate content of dry beans ranges from 24 to 68% on a dry basis of which starch constitutes the major portion which ranges from 24 to 56% (Reddy et al., 1984).

Soluble sugars, comprising monosaccharides and oligosaccharides, makes up only a small portion of the total carbohydrates in legume seeds. The oligosaccharides of the raffinose family (raffinose, stachyose, verbascose and ajugose) range from 31 to 76% of the total sugar (Rockland et al., 1979; Reddy and Salunkhe, 1980; Fleming, 1981; Sathe and Salunkhe, 1981).

The starch of legumes is contained in oblong granules which vary in size and shape by species. The dry bean starch granules are resistant to swelling and rupture, and generally have a high amylose content ranging from 30 to 37% (Hoover and Sosulski, 1985). The temperature of gelatinization (60°C to 75°C) is relatively high compared to cereal which may contribute to processing variability (Hahn et al., 1977).

Recently, dietary fiber has gained increased attention due to its beneficial action in the gastrointestinal tract

(Inglett, G.E., 1979). Hughes (1991) reported dry beans are a good source of dietary fiber which imparts the health related benefits including: a) increased glucose tolerance; b) decreased cholesterol; and c) decreased colonic cancer. Dietary fiber substances are based on carbohydrates and ligin which can not be digested by enzymes in the human digestive tract (Trowell et al., 1976). Plant cell wall materials like lignin, cellulose, and hemicellulose typically constitute the insoluble dietary fiber (IDF), while non-cellulosic polysaccharides including pectin, gums and mucilages make up the soluble dietary fiber (SDF) (Dreher, 1987; Olson et al., 1987). Dry beans, along with other legumes contain a balance of both soluble and insoluble dietary fiber. The total dietary fiber of dry beans ranges from 10.2 to 34% (Anderson, 1989). Hughes and Swanson (1989) reported beans contained approximately 7% soluble dietary fiber and 13% insoluble dietary fiber.

Proteins

Legumes are a valuable source of protein in the diet for several developed nations and also a economic source of protein for many developing countries. In general, the protein content of legumes ranges from 14.9 to 45%. Earle (1982) reported that *Phaseolus* seeds contain approximately 21 to 39% protein. Protein in Legumes can be classified into two types: metabolic proteins and storage proteins. The storage proteins tend to be found in the globulin fractions, while the metabolic (enzymatic or non-storage) proteins are primarily found in the albumin fraction (Deshpande and Nielsen, 1987). The storage proteins are important for their functionality since they make up a higher percentage of the protein in the seed and take responsibility for many physical characteristics of the seed (Boulter, 1981).

Legume proteins possess poor nutritional value unless subjected to heat treatment due to intrinsic factors which reduce digestibility (Trypsin inhibitors) or decrease nutrient absorption (Lectins) (Tobin and carpenter, 1978; Coffey et al., 1985). The improved performance of protein digestibility upon thermal processing is partially attributed to inactivation of these antinutritional factors, such as protease inhibitors and lectins (Nielsen, 1991). Gomez-Brenes et al. (1975) reported that the highest digestibility and Protein Efficiency Ratios (PER) of dry *Phaseolus vulgaris* were obtained after soaking for 8 to 16 hours and cooking at 121°C for 10 to 30 minutes. Over heating resulted in lowered protein quality and decreased availability of lysine.

<u>Lipids</u>

Dry beans usually have a very low lipid content ranging from 1.8 to 2.6% (Korytnyk and Metzler, 1963; Koehler and Burke, 1981). In mature legumes, most of the lipids are stored in the oil bodies (spherosomes) or the lipid-containing vesicle in cotyledons. Several classes of lipids can be found in food legumes: neutral lipids, phospholipids and glycolipids. Neutral lipids are the predominant class of lipids in most of the legume seeds (Salunkhe, et al., 1982; and Drumm, et al., 1990). Phospholipids and glycolipids are essential components of the cellular membranes within the seed and attribute hydrophobic characteristics.

Triacylglycerol, esterified steryl glucoside and phosphatidylcholine were the major identified lipid class components. The fatty acids of dry edible beans are highly unsaturated (78.1%): linoleic and linolenic acids were the major fatty acids (Sgarbieri, 1989; and Drumm, et al., 1990). Apart from unsaturated fatty acids, palmitic acid is the major saturated fatty acid. Usually, the amounts of stearic acid and oleic acid are greater in mature seeds than in immature seeds, and the amounts of linoleic acid and other fatty acids are very low (Young et al., 1972).

Minerals and Vitamins

Food legumes are good sources of minerals, such as calcium, iron, copper, zinc, potassium and magnesium (PAG, 1973). Researchers have shown that the total ash content of *Phaseolus vulgaris* ranges from 3.5 to 4.1% (Fordam et al., 1975; Tobin and Carpenter, 1978 and Kay, 1979). Adams (1972) and Patel et al. (1980) found that the mineral content of navy bean flour is 2 to 17 times greater than that of wheat flour.

It has been commonly observed that the total ash content decreases during cooking due to leaching losses. The ash content loss during cooking ranged from 10% to 70% (Watt and Merrill, 1963 and Meiners et al., 1976). Meiners et al., (1976b) reported the mineral retention in cooked legumes is one third to one half that of the values in raw legumes. Further, it should be noted that the cooking water may contain high levels of magnesium, phosphorus and potassium which as readity absorbed during preparation. Augustin et al. (1981) found the retention of minerals during cooking ranged from a low of 38.5% for sodium to total retention for calcium, with the majority of the minerals remaining at 80-90% of the original level.

Dry beans provide appreciable amounts water-soluble vitamins such as thiamin, riboflavin and niacin. Compared to other common foods, legumes are also good sources of folic acid. Dry beans are almost devoid of ascorbic acid (Watt and Merrill, 1963; Forham et al., 1975; Tobin and Carpenter, 1978). Further, this vitamin will decrease during a lengthy storage. A one-cup serving of cooked legumes (170g, containing 65% moisture) contributes less than 25% of U.S. RDA for thiamin, 10% of the U.S. RDA for niacin and riboflavin, and 10 to 12% of the U.S. RDA for pyridoxine (Vit B_6) (Augustin, 1981). However, Gregory and Kirk (1981) reported that the presence of non-digestible polysaccharides and lignin which compose dietary fiber may reduce the availability of B_6 for intestinal absorption.

Thermal Processing of Legumes

Many researchers have explored innovative alternatives to increase bean consumption. Bean flour has been proposed as a convenient food ingredient to enhance menu versatility and to improve bean utilization. Generally, dry beans are cooked, fried or baked to be used in soups or combined with other foods to make main dishes. Commercially, beans are usually processed in tin cans with brine or tomato sauce and sold as a canned product.

An increase in the utilization of dry beans can be effected through greater understanding of the physical and chemical components of beans, and their effects on the processing functionality and its interactions with final quality acceptability of various bean products (Ruengsakulrach, 1990). The use of this knowledge will encourage the development of new dry bean cultivars and innovative products.

The physicochemical characteristics (structural and chemical components) of dry bean products are affected by several factors (formulation, pH, processing time and processing temperature). Different genetic background, cultural practices and growing environments resulted in variation in physicochemical characteristics (Hosfield and Uebersax, 1980; Ghader et al., 1984).

Soaking and Blanching

Soaking dry beans facilities the cleaning and removal of foreign materials as enabling water uptake to improve process quality aspects of the final product. During soaking and blanching, water and heat induce chemical transformations, such as protein denaturation and starch gelatinization which profoundly influence physical quality attributes.

Antinutritional factors and the flatulence production problem may limit the consumption of legumes. However, soaking may be used to decrease the total sugar content including some oligosaccharides (Silva and Braga, 1982 and Jood, 1986) which are partially responsible for flatulence (Fleming, 1981a; Fleming and Reichert, 1983), and blanching may help to improve the digestibility by denaturing the protease inhibitors (trypsin inhibitor).

Drum-Dried Bean Meal

Instant precooked bean powders have been prepared by soaking, cooking, homogeneous slurring and drum drying (Morris, 1961; Kon et al. 1970; Miller, 1973; Bakker, 1973). Kon et al. (1970) reported that ground raw legumes without pretreatment developed undesirable flavors (odors and taste) because the lipoxidase catalyzes oxidation of unsaturated fatty acids which form hydrogen peroxides and some free fatty acids resulting in rancial off flavors. However, heat treatment (104°C to 105°C) inactived this enzyme activity.

In addition, preheated bean flour destroyed trypsin inhibitors and inhibited hemagglutinin activity. Bakker (1973) reported that drum-dried bean powders were highly acceptable when evaluated by consumer panels. Microscopic examination indicated that little cell rupture and liberation of free starches occurred in drum-dried bean powder. Stored drum-dried bean powder less than 4 to 5% moisture held at room temperature for 12 months, did not possess off-flavors.

PASTA PROCESSING AND QUALITY EVALUATION

Pasta in Modern Dietary Patterns

The National Pasta Association (1991) noted a steady rise in the consumption of pasta from 1980 to 1990. Pasta provides one of the most valuable items for enhancing the nutritional density and reducing the preparation time of meals consistent with meeting modern food selection patterns. The most common wheat variety for pasta product is durum (*Triticum durum*) which produces a relatively less elastic dough, and facilitates the dough mixture to be uniformly forced through small dies at much lower pressures than required for elastic doughs. Durum wheat semolina is the preferred raw material for pasta products because of its suitable protein functional properties and the relatively high pigment content (Irvine, 1978).

Consumers increasingly perceive pasta as an excellent low-fat food, and regard it as a convenient and nutritious food which will enhance the "healthy status" of their diet. Pasta is a low-moisture food which retains nutritional and organoleptic characteristics during storage for many years. In addition, pasta can be manufactured in different sizes and shapes, and can be seasoned with a variety of seasonings, sauces and recipes, offering the consumer more diverse choices. Several additional reasons have enhanced the success and diffusion of pasta within the western diet.

In recent years, an important technology developed to produce convenient products such as "quick-cooking", "pre-cooked" or "instant" pasta. These types of convenience foods provide the consumer with easy preparation, short cooking time, variable choices and balanced nutritional contributions with minimized product waste (Trevis, 1977; Papotto, 1984; Papotto and Zorn, 1985).

The nutrient composition of pasta depends on the ingredients of the dough and the preparation methods. The composition of traditional pasta is very similar to that of durum wheat flour, with the exception that pasta contains higher reducing sugar than durum wheat flour, due to the changes in the carbohydrate components during the extrusion process (Lintas and D'Appolonia, 1973).

Fortified pasta

Pasta is to be considered primarily as a protein-energy food. Lysine is the major limiting amino acid for wheat flour, while lysine is one of the most abundant of the essential amino acids in legumes. According to Bahnassey et al. (1986a), the amino acids contents of spaghetti made with legume flours or protein concentrates has an improved balanced content of lysine and sulfur amino acids than spaghetti processed from 100% durum wheat semolina. Furthermore, pasta helps to reduce the risk factors associated with cardiovascular disease due to its low fat and low cholesterol properties (Mariani-Costantini, 1988). Therefore it is suitable to incorporate cereal flours with legume flour or protein-rich substances to improve their protein quality (Pagani, 1985). Thus, fortified pasta possesses potential as an important role for the improvement of the nutrient content in the modern convenience food based diets.

In the United States, most macaroni products are often enriched with "B" complex vitamins. In addition, several ingredients have been assessed as substitutes in durum pasta products including: 1) legumes (Morad, 1980; Bahnassey et al., 1986; and Duszkiewicz-Reinhard, 1988); 2) rice flour (Kwee, 1969); 3) nonfat dried milk (NFDM) (Glabe, et al., 1967); 4) milk protein - whey protein (Durr, 1973 and Seibles, 1975); 5) soy flour (Paulson, 1960 and Hoskins, 1961); 6) yeast protein (MeCormick, 1975); and 7) fish protein (Woo, 1971). Although some of the cooking characteristics of fortified pasta products are different from traditional pasta, most fortified pasta products are acceptable to consumers.

Manufacture of Pasta Products

In traditional pasta production, durum wheat flour is mixed with water to produce a dough containing about 30% moisture (Matz, 1991). The mixed dough is processed and extruded through a die to produce different shapes of products, such as spaghetti, macaroni, or alphabets, and subsequently dehydrated to a shelf stable food.

Extrusion

Food extrusion provides a versatile technology, since it can be applied to the processing of a wide range of raw materials and can simplify the shaping and forming of a plastic or dough-like material by forcing it through a restriction or die. Rossen and Miller (1973) defined this technology as "... a process in which a food material is forced to flow, under one or more of a variety of conditions of mixing, heating, and shear through a die which is designed to form and/or puff-dry the ingredients."

Cold extrusion technology, which combines with transportation, mixing, and shaping operations, was first applied in pasta production in 1935. The method has been widely used in bakery, candy and pasta industries (Rossen and Miller, 1973). Rotating screw flights transport and mix semolina, flour, water and the other ingredients into a uniform dough-like mass that is subsequently pressed through a special die to obtain the desired product shape. Little frictional heat is generated when deep flight or low shear extrusion screws and smooth barrels are used (Harper, 1978).

Recently, the engineering and design improvements in thermoplastic extrusion systems have been developed to enable continuous high-temperature, short-time (HTST) processing resulting in a major breakthrough throughout the food industry (Smith and Ben-Gera, 1980). Extrusion provides a means for space-intensive, energy-efficient, and economic continuous processing with little waste, highly versatile productivity and high product quality.

The basic components of a HTST extrusion system may include the following procedure (Smith, 1976a; Smith and Ben-Gera, 1980):

(1) uninterrupted feeding of processing materials to the extruder at uniform, controllable feed rates

(2) preconditioning materials with steam under moderate, carefully controlled temperature

(3) selecting an extrusion assembly specially designed to work materials with desired moisture content to form a dough-like mass

(4) controlling dough temperature during the initial time in the extrusion assembly

(5) providing an optimal temperature profile throughout the process by elevating dough temperature for 10 to 30 seconds to the desired extrusion temperature

(6) regulating product resistance time in the extruder to produce the optimal effects of temperature, shearing force and agitation
(7) shaping the extrudate as desired and cutting it into segments of desired length and shape
(8) drying, cooling, particle reduction, and size grading

A typical extrusion cooking system suitable for continuous operation is illustrated in Figure 1.

In response to the enormous popularity of microwave ovens, many manufacturers have altered food properties in order to facilitate the microwave heating process. Most traditional pasta is too thick to be cooked properly in a microwave oven. In order to adapt pasta to be effectively heated by microwave energy, manufacturers have decreased the wall thickness of pasta (Sperber, 1991) or added selected ingredients to improve the rate and capacity of pasta rehydration. In addition, adding glycerol monosterate (monoglycerides are approved emulsifying agents) can improve pasta quality. This emulsifying agent provides good starch complexing properties and reduces the leaching of amylose out of starch granules during heating and minimizes stickiness. Monoglycerides can also improve freezing and thawing stability and decrease the water and sauce absorption after cooking (Matsuo et al., 1986; Giese, 1992).

Drying

Gilles et al (1966) and Banasik (1981) reported that

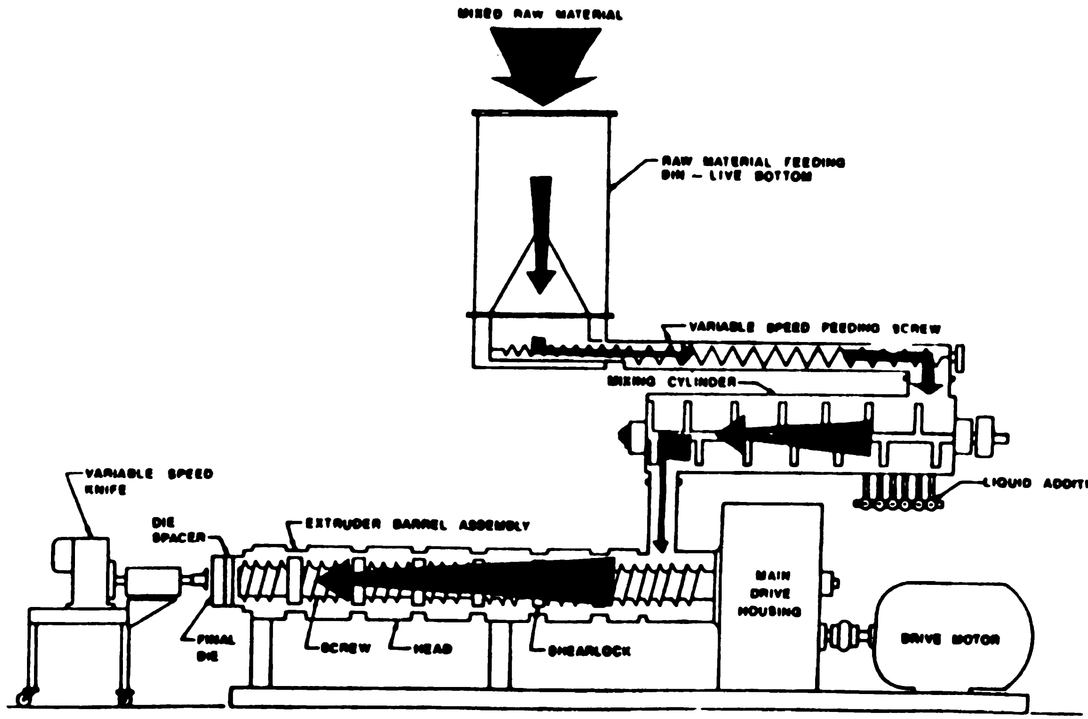


Figure 1. Typical arrangement of high-temperature, short-time extrusion cooker (Smith and Ben-Gera, 1980)

the most difficult and critical process for pasta production is the drying process. The objective of drying is to lower the moisture content of the pasta products from approximately 31% to a range of 13 - 19% so the pasta will become translucent, retain its shape and store without shattering. Drying too slowly will cause products to spoil or mold, while drying too quickly will cause the products crack or check.

Drying affects pasta's shelf-life stability and overall quality acceptance upon rehydration. Drying technology applied to pasta production varies greatly and is primarily associated with drying rate. Air flow rate and air temperature used for the final drying are major control points influencing quality. Traditionally, pasta drying cycles use low temperatures (58 - 60°C) (Dalbon and Oehler, 1983). In recent years, drying pasta products using high temperatures (above 70°C) has become widely accepted by pasta manufacturers (Mauser, 1979; Pavan, 1980). The initial purpose for high temperature drying of pasta was to enable shorter drying cycles and reduce drying time. In addition, high-temperature drying of pasta exhibited equal or better color than low temperature pasta drying schedules. Another benefit for high-temperature drying pasta is improved strand strength and cooking qualities (Dexter et al, 1981), since high-temperature drying processes (above 60°C) allow protein to form a better coagulated network

(Pagani, 1986; Resimi and Pagani, 1983). Moreover, high-temperature drying results in a reduction of the microbial contamination during the drying process (Mauser, 1983).

Pasta drying involves two processes: a) the evaporation of moisture from the surface of the products, and b) the diffusion of moisture inside of the dough to the surface (Giese, 1992). Drying too fast will cause fragmentation and fractures while drying too slow will result in the waste of time and energy. Using very high temperature (above 100°C) drying processes impart a greater plasticity to the dough than using conventional temperature drying processes. The greater plasticity throughout the drying process eliminates the strain phenomena encountered in the traditional process (Ollivier, 1986).

Pasta drying should be considered not only as a water extraction process but also as a cycle in which the taste, color and consistency of the end product are developed. Many factors influence the outcome of the drying cycle, such as pasta shape, temperature and relative humidity of the drying air, and the length of drying time. Therefore, these factors must be specifically evaluated for an individual product and controlled by adequate instrumentation.

Pasta Quality

The appearance characteristics of dry pasta products generally considered to influence acceptability by consumers include: a) appearance of translucent and bright-yellow color; b) freedom from cracking and checking; and c) surface uniformity with relatively few black, brown or white specks. Furthermore, there are some other important factors such as: cooking characteristics; sensory properties; and storage stability which affect consumer perceptions of pasta qualities.

Color

One of the most critical factors affecting pasta acceptability for consumers is the color of the dry and cooked products. The color of pasta depends primarily on the raw materials and process procedure employed. For traditional durum wheat based pasta, the preferred color is bright yellow. It is provided by yellow pigments in durum wheat such as carotene (1%) which is the best known, and lutein (xanthophyll) and its ester pigments are the most abundant (84.8%) (Lepage and Sims, 1968).

The natural yellow color of durum wheat flour is partly lost during dough mixing because of a complex process of carotenoid oxidation which results in the production of colorless degradation products (Matsuo et al, 1970). The "brownness" of macaroni can be improved during the drying process by controlling the Maillard reaction (Matsuo, 1967).

Cooking Quality

Generally, strong gluten (the major wheat protein) develops alimentary pasta with superior cooking characteristics. The cooking quality of pasta is generally regarded as the ability to maintain good texture and not to become a thick or sticky mass after cooking for a normal time. In addition, aroma and taste of pasta are very critical for consumer acceptance. Ideally, "good" pasta will neither be rubbery nor be soft, mushy or soggy. After cooking, pasta should look moist rather than gummy. All pasta pieces should be separate and have a uniform texture (Kummer, 1986). The Italian designation "al dente" means to have moderately firm texture and is terminology commonly used to describe desirable textural properties of pasta.

No standard laboratory method exists for pasta cooking quality evaluation. In Italy, researchers and pasta manufacturing laboratories employ an evaluation of stickiness, resistance to flattening, and bulkiness of cooked spaghetti. According to the definition of Vasiljevic and Banasik (1980), the cooking quality of pasta is a measure of cooked weight, cooking loss and cooked firmness of the product after cooking under certain conditions. The characteristics were defined as follows: 1) cooked weight is the weight of the cooked pasta and is a measure of its water absorption characteristics; 2) cooking loss is the percent solids lost to the cooking water (recommended not to exceed 9%); and 3) cooked firmness refers to the chewing characteristics of the pasta.

During the cooking process, the starch granules imbibe water, swell and gelatinize. Water penetration and starch gelatinization depend on the quality of surrounding protein network. Holliger (1963) found that spaghetti containing low protein levels (9%; 14% moisture basis) imbibed more water and had higher cooking loss than that of high-protein spaghetti (14%; expressed on a 14% moisture basis). In addition, gluten quality and quantity also influenced pasta quality (Sheu et al., 1967; Dahle and Muenchow; 1968, Matsuo and Irvine, 1970; Grzybowski and Donnelly, 1979). Walsh and Gilles (1971) found albumin content to be negatively correlated with cooking losses while high gliadin content appeared to be related to low cooked weight, low cooked firmness and high cooking loss.

A reduction of protein matrix cohesion appeared as a retracted protein network with unprotected starch granules and numerous fissures and crevices. Loss of cohesion caused the reduction of mechanical breaking strength, reduced water absorption and increased cooking loss (Evans et al., 1975).

<u>Texture</u>

There are several different definitions for food texture: Szczesniak (1963) defined it as "the composite of the structural elements of food and the manner in which it registers with the physiological senses"; Kramer (1973) defined it as "... one of the three primary sensory properties of food that relates entirely to the sense of touch or feel and is, therefore, potentially capable of precise measurement objectively by mechanical means in fundamental units of mass or force".

The texture of cooked pasta is usually measured by both sensory and instrumental methods. Many instruments have been utilized for measuring the physical characteristics of pasta. For example, Binnington et al. (1939) determined a "tenderness score" for macaroni products using a compression/creep-type test; Karacsong and Boros (1961) developed a torsionmeter to mechanically measure macaroni quality; Holliger (1963) developed an apparatus to measure the stretching and bending properties of cooked and uncooked spaghetti; and Matsuo and Irvine (1969) defined a "tenderness index" to describe the tenderness of cooked spaghetti.

The most common instrument to test cooked spaghetti firmness is the Instron Universal Testing Instrument with a special Plexiglas® "tooth" (Walsh, 1971; Breen, 1976; Hanna et al., 1978; Bahnassey, 1986b). The instrument was designed for studying the stress strain properties of materials. It tests the tension, compression and bending properties of cooked spaghetti. Briefly, the machine consists of two parts: the drive mechanism, and the force-sensing and recording system (Bourne et al., 1966). Another instrument for testing cooked spaghetti is the Ottawa Texture Measuring System as described by Voisey et al. (1973 and 1978).

Perhaps the most versatile texture measuring instrument suitable for cooked pasta is the Kramer Shear Press which was developed at the University of Maryland by Dr. Amihud Kramer (Kramer et al., 1951; Decker et al., 1957; and Kwee, 1969). The system is driven hydraulically and the force is measured by a force transducer ranging from 0 to 3000 lb capacity. The standard test cell of the texture press consists of a metal box with internal dimensions 2⅝ x 2⅞ x 2½ in. height (6.6 x 7.3 x 6.4 cm). A set of ⅛-inch wide bars, spaced ⅛-inch apart, are fixed at the bottom of the box. A set of ten blades is attached to a press ram. A metal lid containing a set of ten bars that match the bars in the bottom fits over the box (Bourne, 1982). The test samples are placed in the standard test cell and covered with the lid. When the ram is activated, the multi-blades are forced down through the box, first "Compressing" and then "Extruding" the material. The moving blades are propelled downward until they pass between the bars in the bottom of the cell. Szczesniak et al. (1970) studied the relationship between the weight of material in the cell and the maximum force during the compression stroke, which is shown in Figure 2. For most foodstuffs, the force per sample weight is not constant but stabilized when the sample weight increases.

Sensory Evaluation

"Sensory evaluation" has been defined by the Sensory Evaluation Division of the Institute of Food Technologists

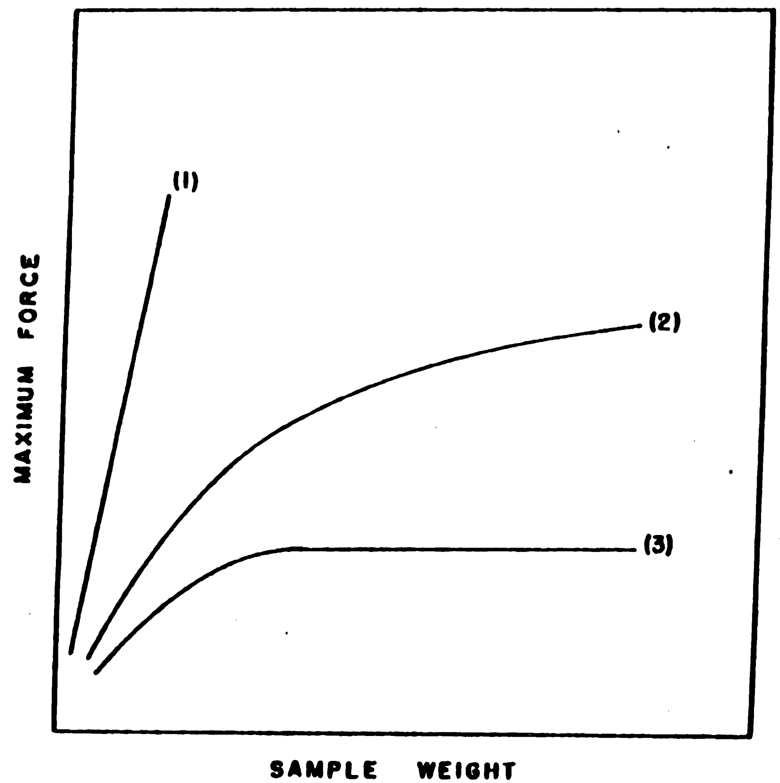


Figure 2. Typical maximum force versus sample weight relationship for standard texture press test cell: (1) white bread and cake; (2) raw apples and cooked dry beans; (3) canned or frozen vegetables (Szczesniak et al., 1970)

(IFT 1975) as: "... a scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the sense of sight, smell, taste, touch and hearing." Sensory evaluation involves the measurement and evaluation of the sensory characteristics of foods. It also involves the interpretation of panelists' responses. Sensory evaluation of foods can provide data and important information essential to successful marketing of new products (Stone, 1985).

There are two major classifications of sensory tests: a) analytical test, which involve laboratory evaluation of products for differences or similarities and for identification and quantification of sensory characteristics; b) affective tests which evaluate preference and acceptance of products and require a large number of untrained panelists (IFT, 1981).

Using sensory evaluation techniques for fortified pasta products is very important. Most sensory evaluation tests have used hedonic scale methodology where panelists judged the samples based on color, appearance, textural and flavor properties. Duszkiewicz-Reinhard (1988) reported that spaghetti fortified with legume flour and navy bean products was preferred by panelists over spaghetti fortified with legume protein concentrates. Bahnassey (1986b) also found that spaghetti supplemented with legume flours was more acceptable than legume protein concentrates. However, spaghetti made with 25% nonroasted legume flours was termed to possess a more "beany" taste than the other formulations. Nielsen (1980) indicated that pasta fortified with precooked pea products improved the flavor while pasta fortified with raw pea flour obtained a poor flavor score. Brown (1988) trained 12 panelists to evaluate spaghetti and meat sauce on a 15 cm unstructured line to describe differences among holding treatments. The data showed a highly significant linear relationship between the sensory scores and shear force values for firmness of spaghetti.

Stone et al. (1974) first introduced the "Quantitative Descriptive Analysis" (QDA) method which allowed a more sensitive means for measuring and reporting data from sensory evaluations. Descriptive analysis provides a complete word description of a product's sensory properties which allows a subject to exclude certain sensations, and for example to evaluate the taste and appearance independently.

Investigations were have been made to determine the relationship between a taste panel's texture evaluation and certain mechanical and ingredient properties. The combination of the rupture force and a "creep recover factor" proved to be a relatively good predictor of the texture quality for cooked products (Hanna, 1978). Voisey (1978) found the cutting forces (Ottawa Texture Measurement

System) to be correlated with sensory evaluation of adhesiveness, firmness, springiness and rate of breakdown of the spaghetti in the mouth. The samples were scored by an unstructured descriptive method to demonstrate the individual sensory characteristic. In addition, instrumental data showed that spaghetti toughness increased logarithmically with the increase of deformation rate used to cut the sample.

Storage Effect

Generally, increasing storage temperature will enhance the chemical reaction rate and decrease the shelf life of foods. Further, the relative humidities of the immediate environment directly affect the moisture contents, and water activity (Aw) of foods both of which influence the rate of food deterioration reaction (Labuza, 1969). Many deteriorative reactions increase exponentially with increasing Aw above the value corresponding to the monolayer moisture content.

It is generally recognized that the equilibrium relative humidity (ERH) value or water activity (Aw) are more closely related to food product stability than to moisture content of foods. Food products stored in various relative humidities will take on or give up water to reach equilibrium moisture content (EMC). The EMC can be plotted against the ERH or Aw to obtain the sorption isotherm curve. This define the hydration process of a food within three ranges of Aw: monolayer water region (Aw < 0.3), multilayer region (0.3 < Aw < 0.7) and capillary condensation region (Aw > 0.7) (Wolf et al., 1972).

Pasta is hygroscopic, it will take up water from, or give it up to, the immediate surrounding atmosphere until a state of equilibrium is achieved. Usually, the finished product has a moisture content of approximate 11%, on a wet weight basis, and is in equilibrium with about 60% RH at 25°C. Pixton and Warburton (1973) found that the safe storage moisture content for macaroni was between 12% and 12.8%, depending on the treatment of the macaroni products. They studied the moisture content and equilibrium moisture humidity relationship for macaroni held under three temperatures (15, 25 and 35°C). The relative humidity in equilibrium with a fixed moisture content is higher at higher temperatures, and consequently the moisture content in equilibrium with a fixed relative humidity is lower at higher temperatures. In addition, water content causes a fissuring of the surface of dried pasta because of changes in the surface tension.

Duszkiewicz-Reinhard et al. (1980) studied shelf life stability of spaghetti fortified with legume flours. Products were packaged in plastic bags, stored at room temperature (23°C) and analyzed initially and following one, three and six months of storage. The results showed that the storage time did not affect pasta cooked weight.

However, after one month storage, spaghetti fortified with navy bean flour or protein concentrate showed significantly lower cooking loss. After three months storage, spaghetti formulated with legume flours had the lowest moisture content, and after one and six months, the color change was not significantly different.

MICROWAVE HEATING

Heating foods may simultaneously occur in three ways: (1) convection - transfer of heat from a source, through air or fluids to food; (2) conduction - molecular transfer of heat within a food or container, from an area of high temperature to an area of low temperature; and (3) radiation - absorption of energy quanta from an electromagnetic wave by food (Knutson, 1987).

Microwave heating is functionally different from traditional conventional heating. Conventional heating transfers thermal energy from the product surface toward the center. In contrast, microwave heating is primarily do to the generation of heat within the foods by absorbed microwaves which are generated by a magnetron. The megnetron is a device that converts electrical energy at low frequencies (e.g. 60 Hertz) into an electron magnetic field with a positive and a negative charge that oscillate billions of times per second. When the microwaves enter the product, they interact with regions of positive and negative charges on water molecules (electrical dipoles). Alignment of dipole molecules of the medium with the microwave field create friction among molecules and result in heating of the product. The heat is transferred through out the product by conventional thermal conduction (Knuts, 1987; Mudgett, 1989).

The dielectric properties of food are primarily determined by moisture and salt contents (Swami and Mudgett, 1981). Generally, the higher the moisture and salt contents, the shallower the microwave penetration depth and the less uniform the heating rate throughout the products. Both 915 Mhz and 2450 MHz microwaves are often used to heat food. Even though 915 MHz microwaves penetrate the food deeper, the use of 2450 MHz microwaves predominates for domestic use.

Several factors affect microwave heating of food, including: a) initial temperature (the higher the initial temperature, the faster it will be heated by microwaves because of higher absorption rate of energy), b) density and homogeneity (the more homogeneous food, the greater and more uniform the absorption of microwaves by the food), c) product shape, d) quantity of food, e) utensils, and f) the distribution of energy within the chamber (Harrison, 1980).

Currently, the microwave oven has been accepted by most consumers because of several advantages compared to conventional ovens: quickness, convenience, ease of cleanup, decreased cost of electricity, and usefulness for defrosting frozen food. According to the National Bureau of Standards (Trub, 1979), microwave heating is more efficient than conventional heating (40% vs 7-14% for conventional ovens). Microwave heating has been observed to use 75% less energy than conventional heating methods (Decarean, 1975 and Richardson et al., 1984). In addition, using microwave energy saves time in food preparation, increases the consumers' acceptability of foods, and improves the nutritive quality of foods (Hoffman and Zabik, 1985; Gordon and Noble, 1959). Therefore, microwave energy possesses great potential for the future and has potential for commercial food processing and food preparation applications.

MATERIALS AND METHODS

SOURCE OF MATERIAL AND SAMPLE PREPARATION

Durum Wheat Semolina

Commercial Durum Wheat Semolina (Patent enriched semolina) was purchased from commercial sources (North Dakota Mill, Grand Forks, ND). Semolina was milled from durum wheat (*Triticum durum*) and sized to pass completely through a 30 mesh (US Standard) sieve and to have a maximum of 3 percent pass completely through a 60 mesh (US Standard) sieve. All flour contained enrichment nutrients (Thiamin, Riboflavin, Niacin, Iron and Calcium) as specified by the U.S. Food and Drug Administration and the USDA Agriculture Stabilization and Conservation Service (ASCS).

Drum-Dried Bean Meal

Commercial class whole raw navy beans (*Phaseolus vulgaris*) obtained from Co-op Elevator Co. Pigeon, Michigan were cleaned, screened and packaged in 100 pound polypropylene bags and held at 4°C (40°F) until processing. Drum-dried bean meal was produced following the procedure of Occeña and Uebersax (1992) as illustrated in Figure 3. Whole dry navy beans (*phaseolus vularis*) were soaked for 16 hours at 25°C then were subjected to hot water extraction at 60°C (140°F) for 60 minutes. Hydrated beans were wet milled

Whole dry navy beans

Soak 16 hrs at 25°C (77°F)

Blanching
60°C (140°F), 1 hr

Rinse

Mill to bean slurry

Heating to 95°C (203°F)

Drum-drying

Flakes

Grind to bean meal
(to pass through 0.07 cm sieve)

Figure 3. Hot water extraction procedure for drum-dried bean meal (Occeña and Uebersax, 1992)

to a homogeneous bean slurry using a Fitz Mill (Model D, Comminuting Machine, The W.J. Fitzpatric Co., Chicago). The leachate of extracted and cooked beans was replaced with fresh formulation water. Bean slurry was pre-heated to 95°C (203°F) then dried on a double drum-dryer. The whole process was produced at Gerber Products Company (Fremont, MI).

Raw Whole Bean Meal

The same commercial class of raw whole navy bean (*Phaseolus vulgaris*) obtained from Co-op Elevator Co. Pigeon, Michigan was dry milled by passing through a Fitz Mill (Model D, Comminuting Machine, The W.J. Fitzpatric Co., Chicago) equipped with 0.07 cm sieve. After milling, raw whole bean meal (RWBM) was mixed directly with durum wheat flour to produce a composite flour which was used to prepare the pasta.

Pasta Processing

Precooked (quick cook or instant) pasta formulations were produced using a Wenger extrusion system (Fig 4) manufactured by Wenger Manufacture Co., Sabetha, KS. which provided continuous high temperature, short time (HTST) processing.

Approximately four hundred pound formulations based on Durum Wheat Semolina, blended with either Drum-Dried Bean Meal (DDBM) or Raw Whole Bean Meal (RWBM) were prepared. Each formulation contained 1.5% Myvaplex (Concentrated Glycerol monostearate, Eastman Chemical Products, Inc.,

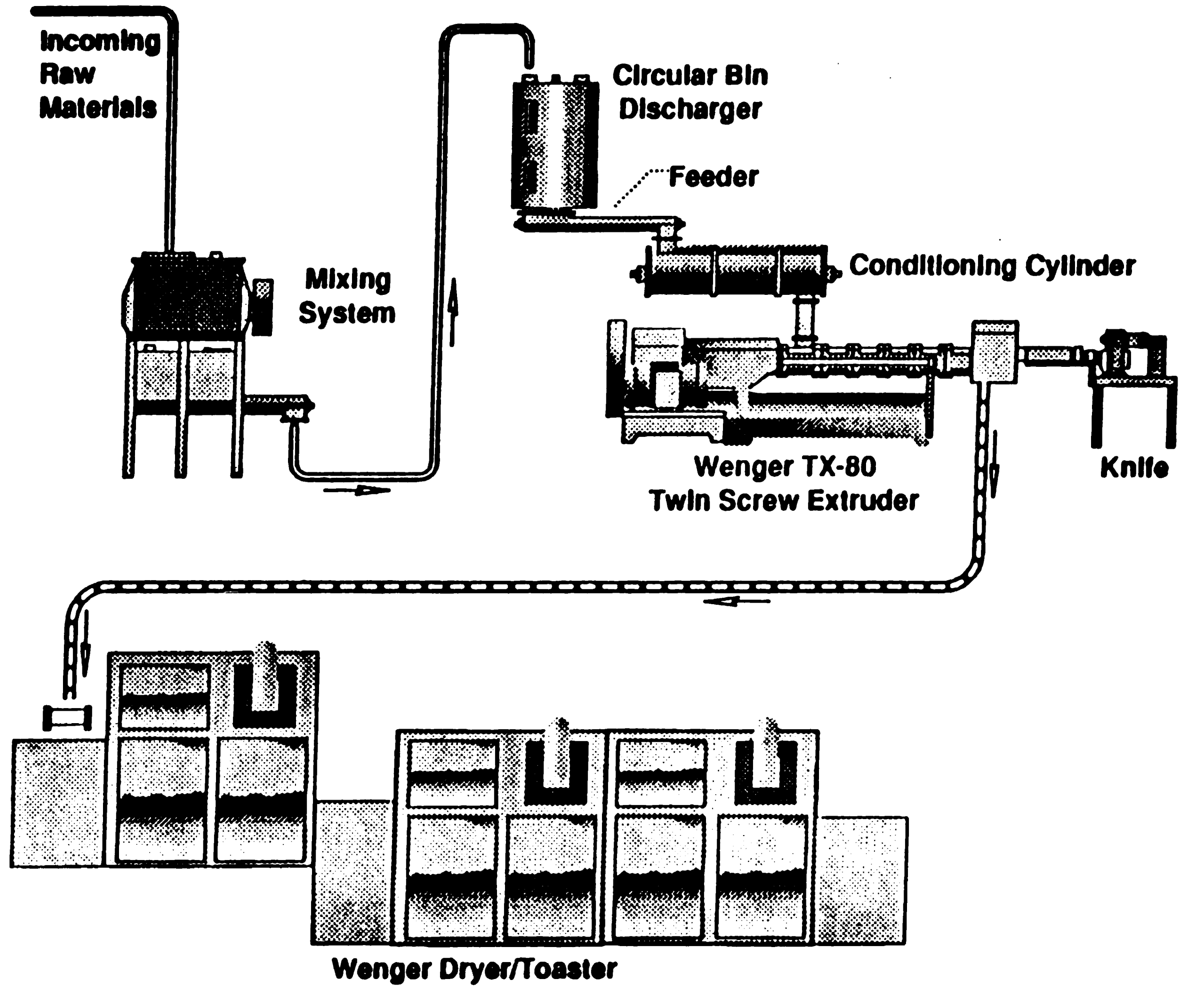


Figure 4. Wenger extrusion and dryer systems (Sabetha, KS)

Kingsport, Tenn) to minimize stickiness and to improve tolerance of overcooking while the product flowed through the extruder.

The treatment designations used for precooked pasta and formulation ingredients are presented in Table 1.

Mixed dry flour ingredients were fed from the hopper into the extruder barrel at a uniform controlled feed rate of 7.5 lbs/min. Preconditioning of the process materials with steam and water at a moderately controlled temperature of 99°C (210°F) partially precooked the mixture by steam injection. Following this preconditioning step, the mixture was augered into a jacketed twin-screw extruder (Model TX-80, Wenger MFG, Sabetha, KS). The preconditioned dough passed through three separate heating zones to achieve a mass temperature of 93.3 - 121°C (200-250°F). A vacuum head of 13" Hg was maintained in the transfer auger to minimize defects in the finished product caused by trapped air bubbles (Anonymous,1981). A constant extruder speed of 154 rpm was maintained to express the dough through the shaping die. Air separated rotatory cutting knives were used to length cut the formed thin-walled macaroni. These "short goods" were conveyed to a dryer/cooler (Series IV, Wenger MFG, Sabetha, KS) held under a constant temperature of 71.1°C (160°F) for 40 minutes retention time.

Collected precooked dry pasta was stored in polyethylene bags, packed in cardboard boxes and held at

Table 1: Name of precooked pasta treatment and formulation ingredients

Treatment Name	Formulation Ingredients
Control Pasta (Control)	400 lb Durum wheat flour 6 lb Myvaplex
15% Drum-dried bean meal pasta (15% DDBM)	340 lb Durum wheat flour 60 lb Drum-dried navy bean meal 6 lb Myvaplex
25% Drum-dried bean meal pasta (25% DDBM)	300 lb Durum wheat flour 100 lb Drum-dried navy bean meal 6 lb Myvaplex
15% Raw whole bean meal pasta (15% RWBM)	294 lb Durum wheat flour 52 lb Raw whole navy bean meal 5.2 lb Myvaplex

room temperature prior to chemical analyses, cooking quality tests and controlled three month storage protocols.

Precooked Dry Pasta Storage Studies

This experiment was designed to evaluate the influence of temperature and relative humidity on the storage stability and cooking quality of precooked pasta. The outline for this storage study is presented in Figure 5.

Duplicate two gram precooked dry pasta samples were dried in a 85°C (185°F) vacuum oven for 10 hours. Pasta samples were stored at 13°C (55°F), 21°C (70°F), and 40°C (104°F) in controlled temperature chambers. Pasta was held under six selected humidities maintained in static desiccators with appropriate saturated salt solutions (Rockland, 1960). Saturated salt solutions were prepared and maintained to form various levels of relative humidity or water activity (Aw) prior to use. The six saturated salt solutions and their corresponding equilibrium relative humidities included: $MgCl_2$ (33% RH); $Mg(NO_3)_2$ (54% RH); $NaNO_2$ (64% RH); NaCl (75% RH); KCl (86% RH); and K_2SO_4 (97% RH). Approximately two weeks were required for precooked dry pasta samples to reach equilibration under the specified relative humidity. During this storage period, the weight gain of pasta samples was recorded every three days until they reached the equilibrium moisture content. The water sorption isotherm was plotted from these data.

The three months accelerated storage study, was

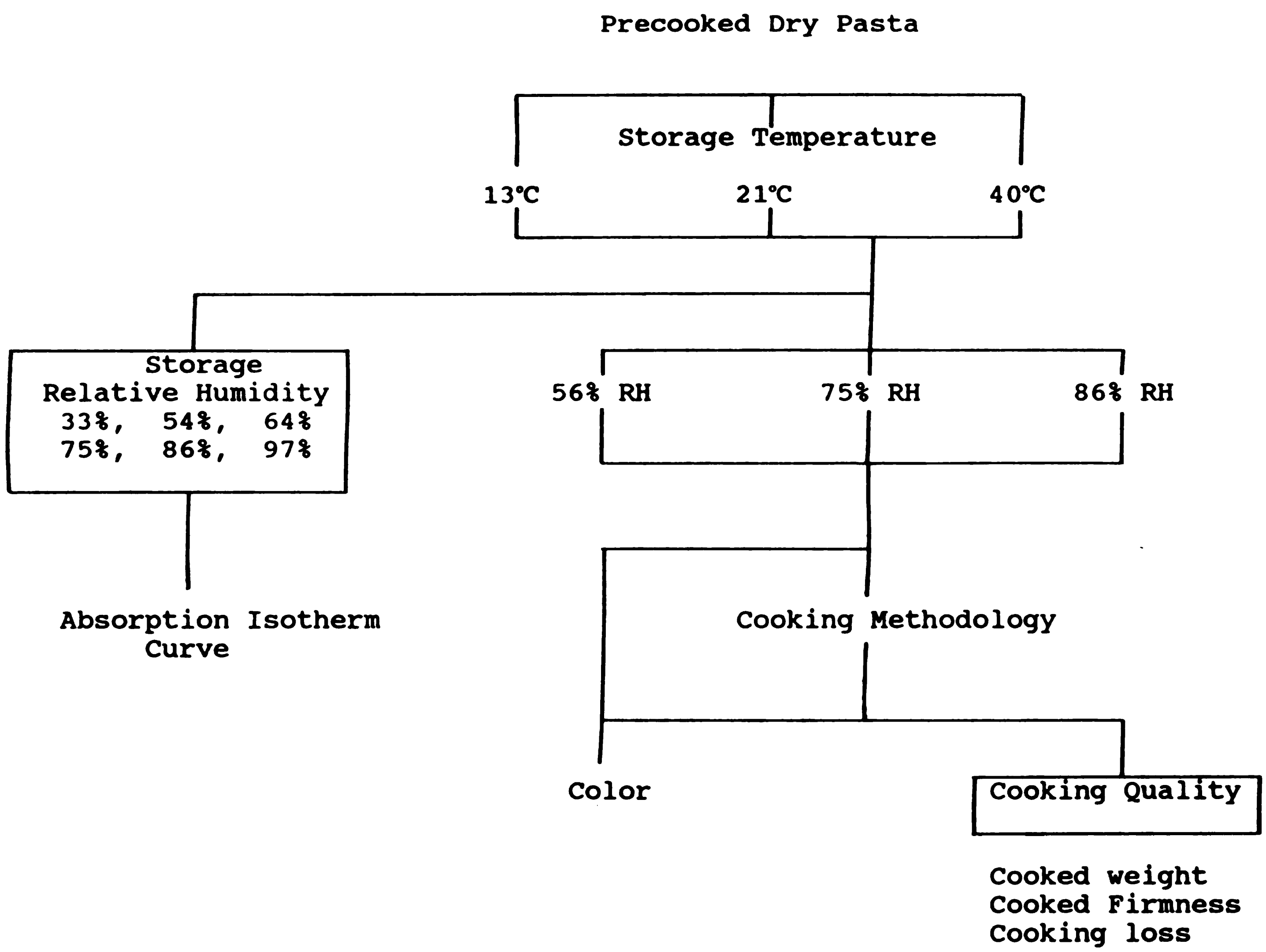


Figure 5. Flow chart outlining protocol of Precooked pasta storage studies

conducted using approximately 150 g precooked dry pasta samples held in polyethylene (PE) bags previously perforated with hundreds of pin holes on the bags surface (1.5 hole/1 cm^2). Bags which contained the pasta samples were heat sealed to a constant size (10 cm x 15 cm) using a Magneta Sealer (MG621, Packaging Aids Corporation, San Rafael, CA). Duplicate samples for each relative humidity treatment were stored in 13°C, 21°C, and 40°C controlled temperature chambers. Selected relative humidity conditions using saturated salt solutions under each temperature were established in well covered static plastic buckets. The saturated salt solutions included: $Mg(NO_3)_2$ (54% RH); NaCl (75% RH); and KCl (86% RH) were prepared and maintained to provide specified relative humidities prior storage. At the end of three months storage, color and weight gain of pasta samples were evaluated. The cooking quality of pasta after this three month storage protocol was also evaluated using conventional and microwave cooking procedures.

PRE-COOKED PASTA QUALITY EVALUATION

Physical-Chemical Analyses

Dry pasta powders were held in small glass jars (100 ml) and stored at room temperature prior to analyses. Samples of approximately 80 gm were randomly selected from precooked dry pasta and dried cooked pasta for each cooking test (collected individually from conventional and microwave cooked pasta and dried in a 110°C air-oven for 10 hours). Pasta samples were milled into powder by passing through a Wiley mill (Arthur H. Thomas Co., PA) equipped with a 30 mesh sieve. Figure 6 shows a flow-chart of the experimental design for pasta formulations.

Color

Pasta color was measured with the Hunter Lab Color and Color Difference Meter (model D25, Hunter Associates, Fairfax, VA). The color meter measures reflectance on three coordinates labeled L, a_L, and b_L. L indicates darkness (0) to lightness (100), a_L represents green (-) to red (+), and b_L means blue (-) to yellow (+). The Hunter instrument was standardized by a white tile with the coordinates L = + 94.5, a_L = - 0.6, and b_L = + 0.4. Approximately 100 g of thin-walled macaroni sample was placed in an optically pure glass dish, covered to prevent interfering light and readings were recorded.

Moisture

The moisture content of precooked dry pasta samples was determined by AACC method 44-40 (1983). Approximately 2 gm pasta sample was weighed into previously dried and tared aluminum moisture dishes and dried in a partial vacuum (25 mm Hg) oven at 90 to 95 °C for 10 hours. Samples were cooled in a desiccator, reweighed and the calculated percent moisture content based on the fresh dry pasta sample weight was performed using the following equation:

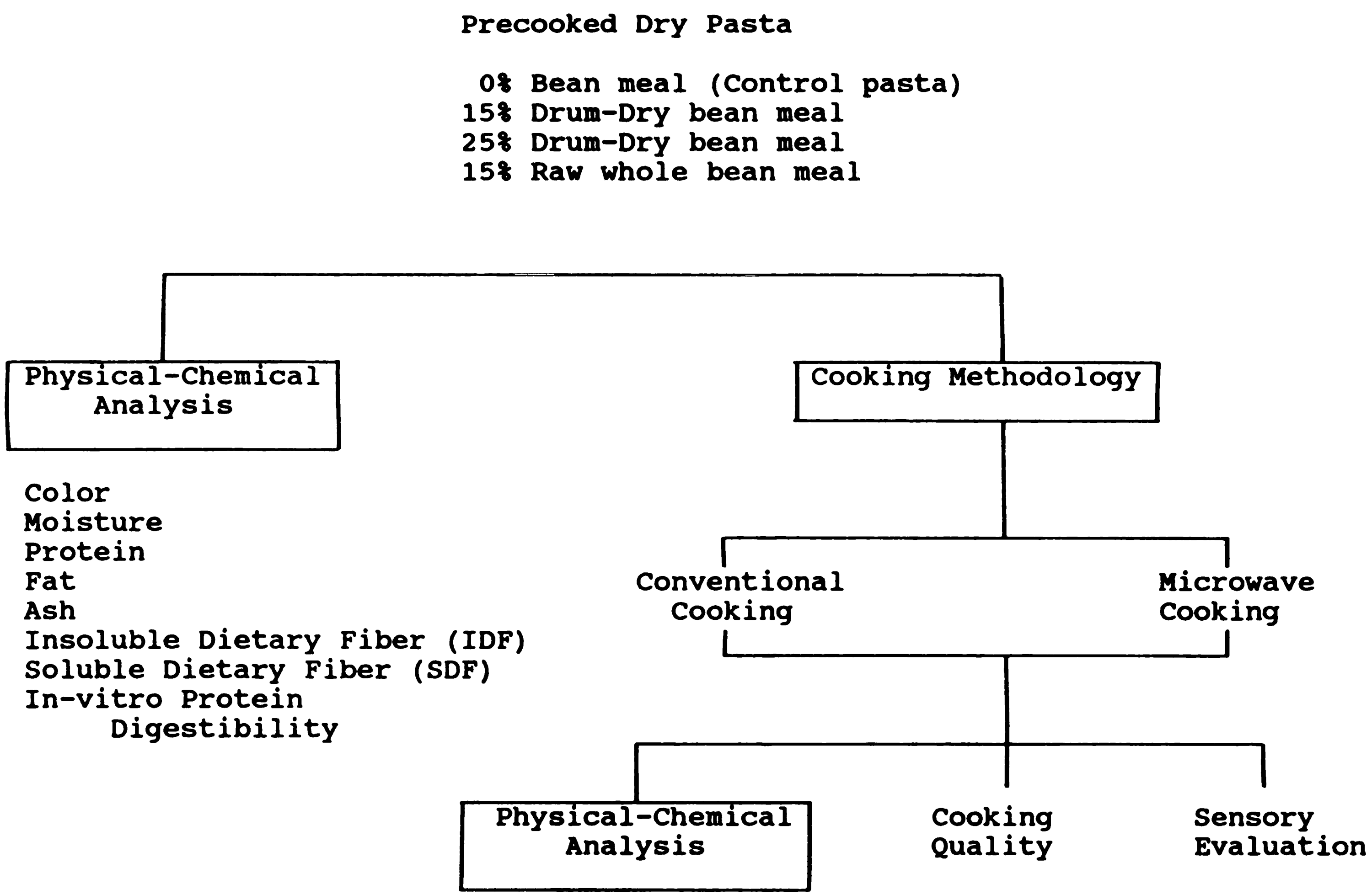


Figure 6. Flow chart of the Physical-Chemical analyses and cooking quality test for precooked dry pasta

$$\text{Moisture\%} = \frac{\text{fresh sample wt(g) - dried sample wt (g)}}{\text{fresh sample wt (g)}} \times 100$$

Protein

The crude protein content of each sample was determined by AACC method 46-13 (1983). Approximately 0.5 g pasta powder was weighed and analyzed by a standard Micro-Kjeldahl procedure. Percent nitrogen was calculated by the following equation:

$$\text{Nitrogen\%} = \frac{\text{(ml HCl - ml blank) x N HCl x eqiv wt NaOH}}{\text{wt of sample (g)}} \times 100$$

Crude protein can be calculated from total nitrogen times the conversion factor 5.70 for wheat flour and 6.25 for navy bean flour.

Fat

The fat content of pasta samples was extracted by the Soxtec System HT6 (1043 extraction unit and 1044 service unit, Tecator AB, Höganäs, Sweden). Approximately 3 gm pasta powder was weighed and placed in Extraction Thimbles. Petroleum ether (45 ml) was filled into dried and pre-weighed fat extraction cups with several glass beads to prevent boiling. Samples were heated and extracted using the "Boiling" position (immersed thimbles and samples in the solvent) for 15 minutes and then placed in the "Rinsing" position to drain (thimbles suspended above the solvent) for 45 minutes. Following the rinsing extraction step, the solvent was evaporated and the extraction cups dried in an air oven (110°C) for 30 minutes. The extraction cups were cooled in a desiccator and weighed at room temperature. The percent of fat content based on the dry weight was calculated using the following equations:

$$\text{Fat \%} = \frac{\text{(wt of cup and fat - wt or dry cup)}}{\text{dry sample wt (g)}} \times 100$$

Ash

The ash content of samples was determined by the method of AACC 08-01 (1983). Known quantities of approximately 3 g were placed into previous dried and tared crucibles and incinerated in a muffle furnace at 575°C for 16 hours. The ash residue was cooled in desiccator and weighed at room temperature and the ash content was calculated on the dry weight basis using the following equations:

$$\text{Ash \%} = \frac{\text{wt of residue (g)}}{\text{wt of dry sample wt (g)}} \times 100$$

Dietary Fiber

The soluble and insoluble dietary fiber (SDF and IDF) contents of samples were determined by the methods of AOAC

985.29 (1990) and Prosky (1988). The complete procedure is presented in Figure 7. The analytical digestive enzymes included: Heat stable α-Amylase (A-3306); Protease (P-3910); and Amyloglucosidase (A-9913) and were obtained from Sigma Chemical Company (St. Louis, MO). The filtration was performed with Tecator's Fibertec system (Tecator AB, Höganäs, Sweden), using 0.5 g of Celite as a filter aid. Both soluble and insoluble dietary fiber residues were dried overnight in a 70°C vacuum oven. Fiber residues were then analyzed for ash (525°C, 5 hours) and nitrogen by the Micro-Kjeldahl method (AOAC 960.52, using 6.25 as conversion factor). Dietary fiber values were corrected for the residual protein and ash. Calculation of the blank for dietary fiber was based on the following equation:

$$B = \text{blank (mg)} = \text{wt residue} - P_B - A_B$$

wt residue = average of residue wts (mg) for duplicate blank determines

P_B = wts (mg) of protein in the first blank residue

A_B = wts (mg) of ash in the second blank residue

Calculation of the soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) was as follows:

$$\text{SDF \%} = [(\text{wt residue} - Ps - As - B)/\text{wt sample}] \times 100$$

$$\text{IDF \%} = [(\text{wt residue} - Pi - Ai - B)/\text{wt sample}] \times 100$$

wt residue = average of wts (mg) for duplicate sample determinations

Weigh duplicate 1 g sample

|

Add 50 ml pH 6 phosphate buffer

|

Add 0.05 ml heat stable α-amylase

|

Incubate in boiling water bath 15 mins
(internal temp = 95 to 100 °C)

| Cool

Adjust to pH 7.5 ± 0.02

|

Add 0.1 ml protease solution
(50 mg protease in 1 ml phosphate buffer)

|

Incubate at 60°C, 30 mins

| Cool

Adjust to pH 4 - 4.6

|

Add 0.3 ml amyloglucosidase
Incubate at 60°C, 30 mins

|

Filter through crucible containing Celite

|

- Continued -

Figure 7. Flow chart of insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) analysis for formulated pasta samples

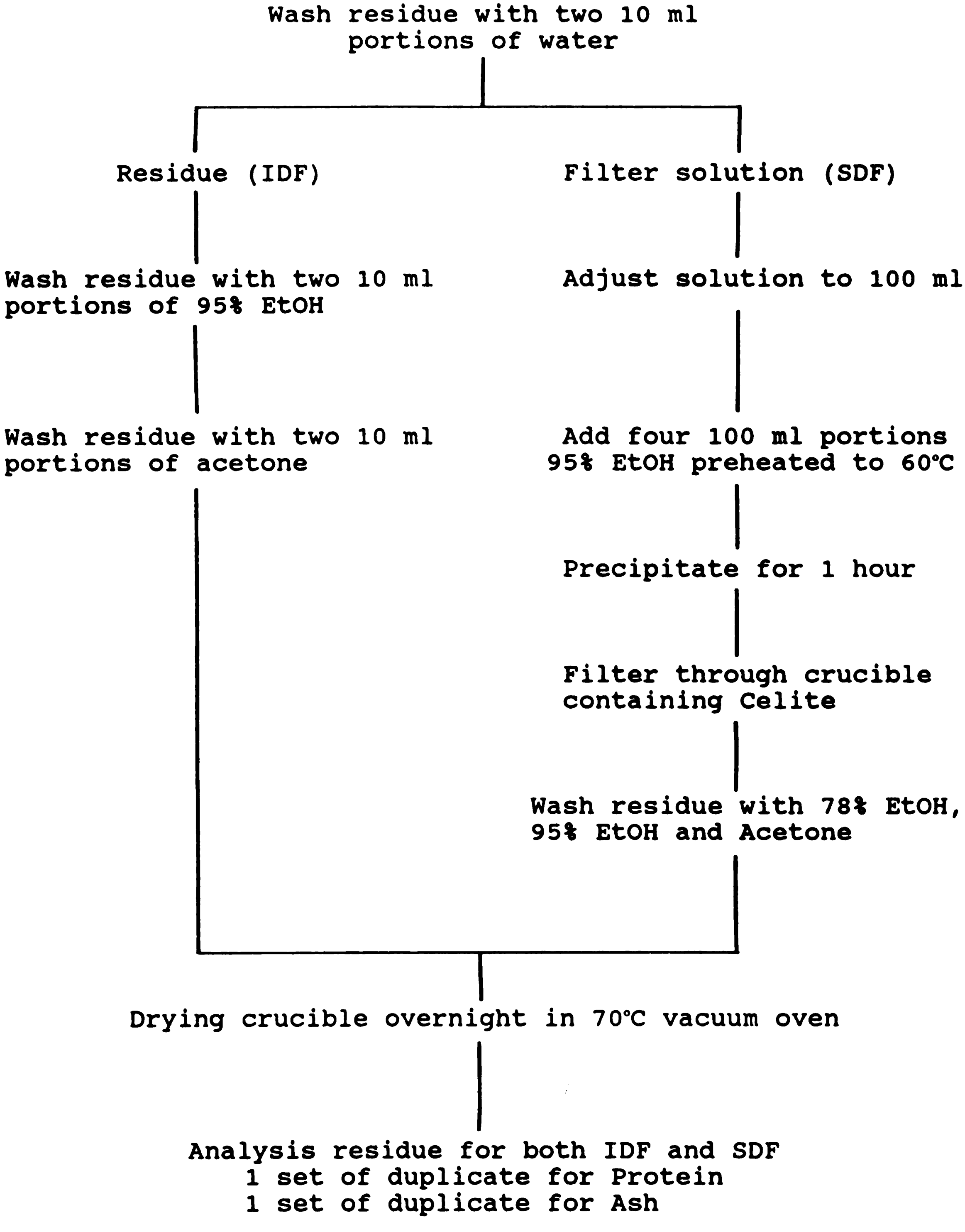


Figure 7. (continued)

Ps and Pi = wts (mg) of protein determined from SDF and IDF residue

As and Ai = wts (mg) of ash determined from SDF and IDF residue

In Vitro Protein Digestibility

The digestibility of protein was based on AOAC 43.265. In-vitro protein Digestibility for C-PER (AOAC, 1984) using casein as a standard was determined by measuring the extent to which the pH of the protein suspension dropped when treated with a multi-enzyme system. The standard casein and enzymes used in the determination included: porcine pancreatic trypsin (Type IX); porcine intestinal peptidase (Grade I); bovine pancreatic α-chymotrypsin (Type II); and bacterial protease (Pronase E), were obtained from the Sigma Chemical Co. (St Louis, MO).

The pH for the standard casein control should be 6.42 $\pm$ 0.05 at 20 minutes after enzyme treatment. Each test sample was carried through identical procedures and read after 20 minutes to obtain pH(x). Percent protein digestibility was calculated using the following equation:

$$\% \text{ Digestibility} = 234.84 - 22.54(x)$$

where (x) = pH after 20 minutes

Cooking Methodology

Approximately 100 g Commercial pasta (Mueller's elbows, CPC International Inc., Englewood Cliffs, NJ) was cooked in

1000 ml boiling water for 8 minutes using a conventional electric stove. Pasta firmness was estimated by measuring "maximum force" with a Kramer Shear Press. The value obtained for Mueller commercial pasta was 850 N/force and was used as a reference of ideal cooking texture value to determine the optimum cooking time of precooked pasta. Preliminary tests were conducted using full microwave power (740 watts) and cooked 100 g control (100% semolina) dry pasta for up to eight minutes are reported in Appendix I. Maximum cooked pasta firmness values were used to determine the optimum cooking time. Furthermore, evaluation of microwave heating power was conducted and included: full power (740 Watts); 80% full power (592 Watts); and 60% full power (444 Watts) (Appendix II).

Conventional cooking

Weighed 100 gm precooked dry pasta was placed into a Corning Ware (A-3-337, 3 Liter Covered Casserole, Corning Incorporated, Corning, NY) with 1000 ml boiling distilled water (Dexter and Matsuo, 1979, Dexter et al. 1981 and Pagani et al. 1989). The water was preheated at "high" temperature to boiling on Kenmore Conventional Stove (Sears Roebuck and Co., Chicago, IL). Each sample was cooked for 2 minutes under continuous boiling condition.

Microwave cooking

Approximately 100 gm precooked dry pasta was placed in Corning Ware (A-3-337, 3 Liter Covered Casserole, Corning

Incorporated, Corning, NY) with 1000 ml room temperature distilled water (22 to 24°C). The covered Corning Ware was placed in the microwave oven (Amana Model RS458P, Amana Refrigeration, Inc., Amana, IW) and cooked at full power (740 Watts) for five minutes.

Cooking Quality

Cooking quality of pasta included the measurement of cooked weight, cooking loss and cooked firmness of the products after proper cooking time (Vasiljevic and Banasik, 1980).

Cooked weight

At the end of conventional and microwave heating to the optimum cooking time, samples were poured onto a US Standard No. 8 screen (0.24 cm opening). The screen was drained at a 15° angle for two minutes prior to weighing. Pasta was weighed and the water absorption was calculated based on the fresh dry pasta weight prior cooking.

$$\text{Water absorption \%} = \frac{\text{cooked weight} - \text{prior cook weight}}{\text{prior cook weight}} \times 100$$

Cooking firmness

Cooking firmness was measured using a Kramer Shear Press (Model TMS-90, Food Technology Corporation, Rockville, Maryland). Approximately 100 gm cooked and drained samples was placed in a Standard Shear-Compression Cell CS-1 (Figure 8, with 10 multiple blades). The samples of cooked pasta

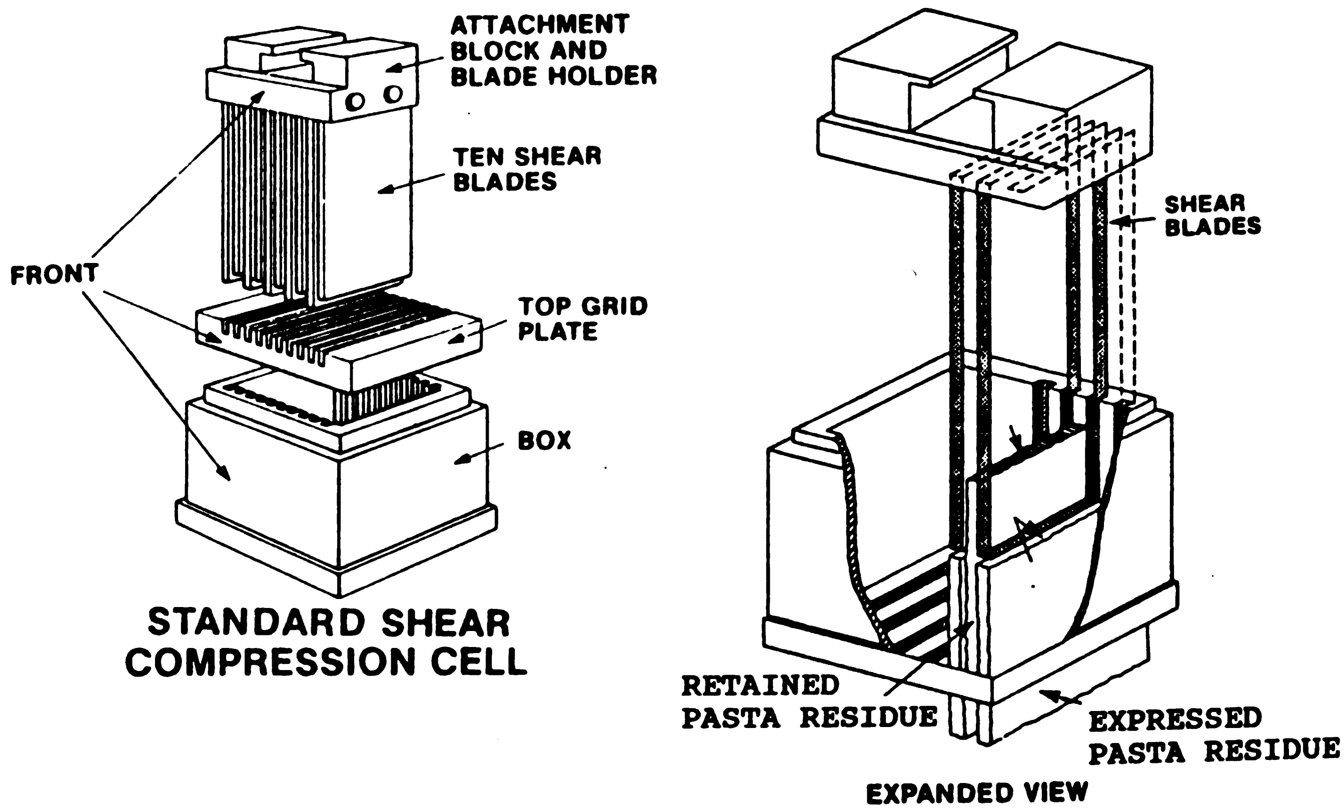


Figure 8. Standard shear compression cell (CS-1) with 10 multiple blades (Uebersax et al., 1988)

were distributed evenly in the cell and sheared. Results of firmness for cooked pasta presented in N force/100 g sample. The firmness was recorded from Kramer Shear Press as the maximum textural peak force of the cooked pasta.

Cooking loss

After proper cooking and draining, all of cooked pasta formulations were collected on aluminum plates and dried in an air-oven (110°C) for 10 hours then cooled and weighed at room temperature. Calculation of pasta cooking loss was based on dry weight basis using the following equation:

$$\text{Cooking loss \%} = \frac{\text{cooked dry wt - prior cook dry wt}}{\text{prior cook dry wt}} \times 100$$

Pasta will lose solids and gain moisture during the cooking process. Calculations which account for these changes assist in data interpretation. The loss of solids is important due to decreases in the nutrient levels in the cooked pasta. These losses can be calculated by the apparent retention of nutrients (AR) and the true retention of nutrients (TR) (Murphy, 1975 and Bender, 1978).

$$\text{AR\%} = \frac{\text{nutrient content per g of cooked food (dry basis)}}{\text{nutrient content per g of raw food (dry basis)}} \times 100$$

$$TR\% = \frac{\text{(nutrient content per g of cooked food)}}{\text{(nutrient content per g of raw food)}} \times \frac{\text{(g of food after cooking)}}{\text{(g of food before cooking)}} \times 100$$

Sensory Evaluation

Quantitative Descriptive Analysis (QDA) (Stone et al., 1974) was conducted by panelists selected and trained to identify and quantify the sensory characteristics of pasta formulations. Pasta formulation samples for sensory evaluation were cooked to optimum cooking time by either conventional or microwave cooking, drained and served warm to sensory panelists. Panelists were provided with a spoon, napkins and rinsing water during the tasting session.

A score sheet (Figure 9) was developed using a ten centimeter unstructured line with marks fixed at 1 cm, 5 cm and 9 cm on the line for describing the product attribute differences. The panelists were asked to evaluate each sample by marking the line where it best represented the attributes. A reference sheet (Figure 10) was provided to the panelist to assist with terminology and to provide points of terminology reference. Panelists evaluated the appearance characteristics of pasta by visual examination for surface characteristics which included: yellowiness, shininess and graininess. Following visual evaluation, panelists tasted the pasta to evaluate the firmness, Name: ____________________

Date: ____________________

Sample Code: ______________

Cooked Pasta Evaluation

Quantitative Descriptive Analysis

Using the reference sheet for sensory evaluation, follow the technique and defined terminology to compare each treatment and the reference sample carefully. Indicate your rating on this ballot by placing a slash for each code number anywhere along each 10 cm line. The fixed marks are located at 1, 5 and 9 cm on each line.

1. Visual:
   Color

   Pale Yellow ___|___________|___________|___ Dark Yellow

   Shininess

   Dull ___|___________|___________|___ Shiny

   Smoothness

   Smooth ___|___________|___________|___ Grainy

2. Texture
   Firmness

   Soft ___|___________|___________|___ Firm

   Chewiness

   Mushy ___|___________|___________|___ Rubbery

3. Flavor

   No bean flavor ___|___________|___________|___ Strong bean flavor

Figure 9. Score sheet for cooked pasta evaluation using Quantative Descriptive Analysis

Reference Sheet of Techniques &

Terminology for Cooked Pasta Evaluation

1. Visual:

Put two to three pasta samples on the white container for your visual examination. In this evaluation, look at the pasta color intensity, the surface smoothness and the shininess.

Color: the degree of yellow as it relates to the reference pasta

Shininess: the degree of shininess of the sample surface

Smoothness: the degree of the sample surface containing small distinct particles

2. Texture:

Pick up some pasta samples (three to five) on a spoon and press them between your tongue and palate to evaluate:

Firmness: the force required to compress the pasta between the molar teeth when biting evenly during the first bite

Chewiness: put samples between molars, chew 10 to 15 times and evaluate for the chewing feel

3. Flavor:

Put two to three pieces pasta in the mouth and chew them for about one to two minutes, swallow them and evaluate for:

Flavor: the degree of bean flavor or other strong flavor in the pasta

Figure 10. Reference sheet for techniques and terminology of cooked pasta evaluation using Quantitative Descriptive Analysis

and bean flavor characteristics. An example of the typical graphical presentation used for QDA results is shown in Figure 11.

Statistical Analysis

The effects of bean meal formulated pasta and cooking methodology on chemical composition were analyzed using the analysis of variance (ANOVA), mean separation, and correlation subprograms of the MSTAT microcomputer statistical program (Ver. 4.0, 1987). The chemical compositions were analyzed as a two-way interaction ANOVA, with cooking methods or pasta formulations and replication as factors. Mean squares were reported significant probability level were set at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). Coefficient of variation (%CV) expresses the standard deviation as a percent of the calculated mean. Least significant difference (LSD) was used for the separation of means. These were used to compare pasta formulations differences.

The differences between the composition of experimental and calculated values were determined using the t-test subprogram of MSTAT. The two sets of data were evaluated by comparing the calculated t value with tabulated t value. When t (calculated) value is higher than t (tabulated) value, it indicated significant (*) difference between these two sets of data .

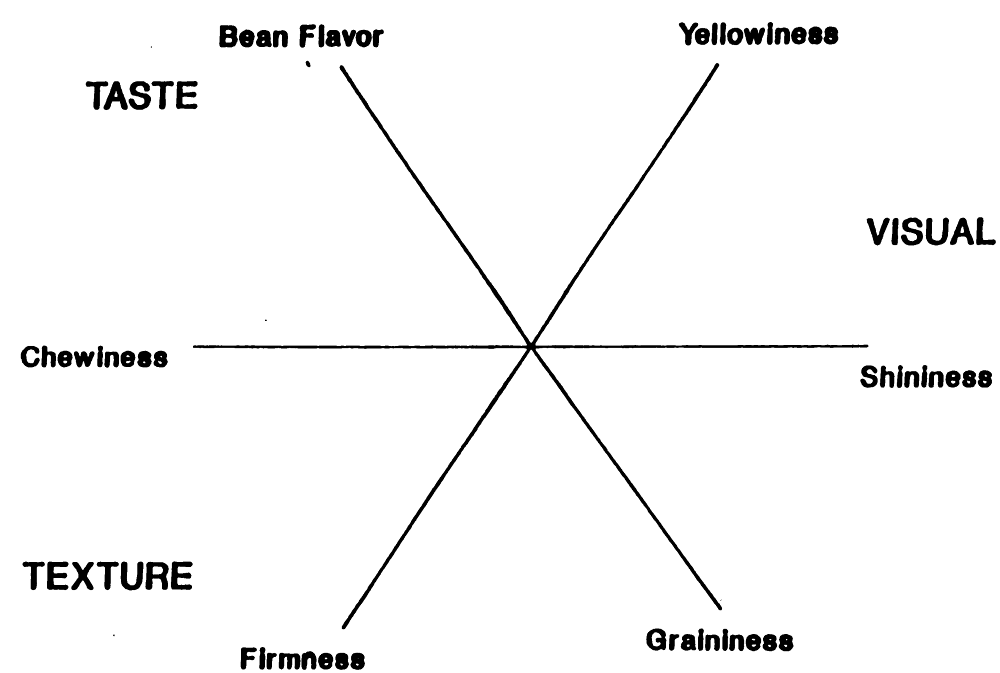


Figure 11. The diagram used in final sensory expression, each attriubute line starts from center: 0 (least) to 10 (most)

RESULTS AND DISCUSSION

Physical-Chemical Characteristics of Extruded Dry Pasta and Cooked Pasta Formulated with Bean Meals

Chemical composition analysis

Experimental mean values and calculated values for proximate composition of raw ingredients and extruded dry pasta are presented in Table 2. This procedure was conducted to assess the acceptability of the ingredient blending and formulation of pasta. Raw whole bean meal had the highest moisture, protein, ash and fat contents among raw ingredients. Evaluation of the extruded dry pasta using a paired t-test indicated that there were no significant differences for experimental mean values and calculated values for protein and ash content. However, the fat content obtained for experimental mean value was much lower than the calculated value. A decrease in fat content of extruded products has been reported and interpreted as monoglycerides and free fatty acids forming complexes with amylose during extrusion cooking which decrease the extractable fat content in extruded products (Fabriani et al., 1968 and Mercier, 1980).

Tables 3 and 4 show the analysis of variance, mean values and Least Significant Difference (LSD) mean

Table 2. Comparison of chemical composition contents mean values[1] in raw ingredients and extruded pre-cooked dry pasta formulated with selected bean meal (Experimental[2] vs Calculated[3])

Ingredients/ Formulations	Moisture %	Protein %		Ash %		Fat %	
		Exp	Cal	Exp	Cal	Exp	Cal
Ingredients							
Durum wheat	10.78	16.35	---	0.70	---	1.09	---
Drum-dried bean meal	11.08	25.00	---	2.69	---	0.87	---
Raw whole bean meal	13.12	25.45	---	3.90	---	1.66	---
Dry Pasta Formulation							
Control pasta	8.81	16.03	16.35	0.78	0.70	0.32	1.09
15% DDBM pasta	8.74	18.50	17.65	1.04	1.00	0.29	1.06
25% DDBM pasta	9.08	19.28	18.52	1.25	1.20	0.38	1.04
15% RWBM pasta	9.90	18.85	17.72	1.26	1.18	0.34	1.18
$T_{0.05}$ Calculated value		0.71		0.39		20.98*	

1. T-test, * = significant at $T_{0.05}$ Calculated value $\geq$ 2.35 ($T_{0.05}$ Tabulated value)
2. experimental values were obtained by AACC (1983) analytical methods
3. calculated values were obtained for the following treatments: Control Pasta, 100% Durum Wheat; 15% DDBM pasta, 85% Durum wheat + 15% Drum-dried bean meal; 25% DDBM pasta, 75% Durum wheat + 15% Drum-dried bean meal; 15% RWBM pasta, 85% Durum wheat + 15% Raw whole bean meal

Table 3. Analysis of variance for chemical compositions of bean meal formulated pasta cooked by conventional and microwave energy

source of variation	df	Protein (%)	Ash (%)	Fat (%)
			Mean Squares[1]	
<u>Main Effects</u>				
Cooking[2]	2	4.25**	0.27**	0.03**
Formulation[3]	3	12.15**	0.30**	0.02**
<u>Interaction</u>				
Cooking x Formulation	6	0.61**	0.01**	0.01**
Error	22	0.01	0.0001	0.001
% CV		0.53	1.13	9.69

1. n=3, * = significant at P ≤ 0.05, ** = significant at P ≤ 0.01
2. cooking treatments include: uncooked dry pasta; conventional cooking (100°C/2 mins); and microwave energy (740 Watts/5 mins)
3. formulations include: 100% durum wheat semolina; 15% drum-dried bean meal; 25% drum-dried bean meal; 15% raw whole bean meal

Table 4. Mean values[1] of composition analysis for pasta formulated with selected bean meals and cooked by conventional and microwave energy

Cooked method/ formulation[2]	Protein (%)	Ash (%)	Fat (%)
Dry Pasta (Uncooked)			
Control	16.03d	0.78c	0.18c
15% DDBM	18.50c	1.04b	0.29b
25% DDBM	19.28a	1.25a	0.38a
15% RWBM	18.85b	1.26a	0.34ab
Conventional cooked pasta			
Control	16.17d	0.57d	0.14b
15% DDBM	17.14c	0.78c	0.25a
25% DDBM	17.67a	0.94a	0.21a
15% RWBM	17.38b	0.88b	0.23a
Microwave cooked pasta			
Control	16.05d	0.65d	0.23c
15% DDBM	18.35c	0.84c	0.26b
25% DDBM	19.10a	1.02a	0.30a
15% RWBM	18.76b	0.97b	0.27b

1. n=3, Least significant difference ($LSD_{0.05}$) mean separation; means followed by unlike letters are significantly different at $p \leq 0.05$ within cooking method (column)
2. pasta (pasta:water = 1:10) cooked by conventional (100°C/2 mins) and microwave energy (740 Watts/5 mins) for the following formulations: Control, 100% durum wheat; DDBM, drum-dried bean meal at 15 and 25% substitution; RWBM, raw whole bean meal at 15% substitution

separation of proximate composition for dry and cooked pasta formulated with selected bean meals. Pasta formulations including control pasta (100% Semolina), drum-dried bean meal pasta (15% DDBM and 25% DDBM), and raw whole bean meal pasta (15% RWBM) were used for analyses. Significant differences were found for both cooking methods (conventional and microwave cooking) and pasta formulations. With an increase in percentage of bean meal making up the formulation, an increase in protein, ash, and fat of the pasta resulted. Figure 12 illustrates protein content for pasta formulations prepared by different cooking methods. For microwave cooked pasta formulations, protein content was not significantly different compared to dry pasta except for 25% drum-dried bean meal pasta. However, the protein content for conventionally cooked pasta formulations was significantly lower than dry pasta formulations except for control pasta.

Mean values of ash and fat contents for dry and cooked formulated pasta are presented in Figures 13 and 14, respectively. Both conventional and microwave cooked pasta had lower ash and fat contents than dry pasta, except that the microwave cooked control pasta had a higher fat content than dry pasta.

Table 5 shows apparent retention and true retention of nutrients in the cooked formulated pasta (based on a solid lost and moisture gain model). Differences between these

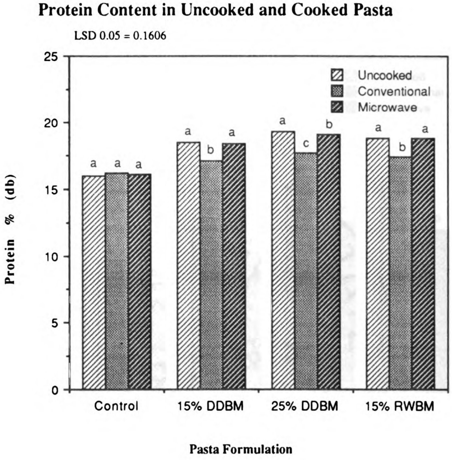


Figure 12. Protein content for uncook, conventional and microwave cooked pasta formulations with control (100% durum wheat), drum-dried bean meal (15% and 25% substitution), and raw whole bean meal (15% substitution); unlike letters with formulations are different at $P \leq 0.05$ among cooking methods

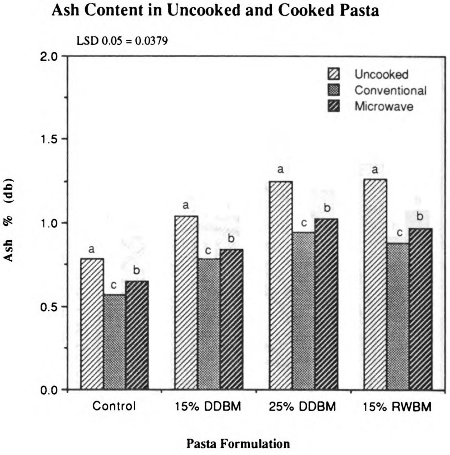


Figure 13. Ash content for uncook, conventional and microwave cooked pasta formulations with control (100% durum wheat), drum-dried bean meal (15% and 25% substitution), and raw whole bean meal (15% substitution); unlike letters with formulations are different at P $\leq$ 0.05 among cooking methods

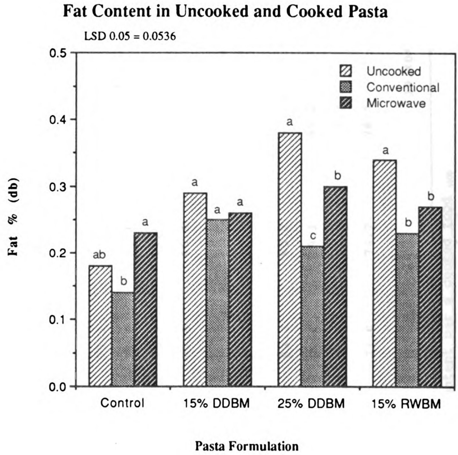


Figure 14. Fat content for uncook, conventional and microwave cooked pasta formulations with control (100% durum wheat), drum-dried bean meal (15% and 25% substitution), and raw whole bean meal (15% substitution); unlike letters with formulations are different at P $\leq$ 0.05 among cooking methods

Table 5. Apparent[1] retention and True[2] retentions of nutrients content after conventional and microwave cooking of formulated pasta[3] using "Solid lost, Moisture gain" model

Cooking/ Formulation	Protein		Ash		Fat	
	Apparent retention (%)	True retention (%)	Apparent retention (%)	True retention (%)	Apparent retention (%)	True retention (%)
CONVENTIONAL COOKED PASTA						
Control	96.8	92.6	73.1	70.0	46.9	44.9
15% DDBM	88.1	83.4	75.0	71.1	82.8	78.4
25% DDBM	87.6	83.6	75.2	71.8	52.6	50.2
15% RWBM	87.9	83.5	69.8	66.4	61.8	58.7
$T_{0.05}$ Cal. value	28.97*		20.80*		7.96*	
MICROWAVE COOKED PASTA						
Control	97.3	93.6	83.3	80.2	62.5	60.2
15% DDBM	97.7	94.5	80.8	78.1	86.2	83.4
25% DDBM	97.0	94.1	81.6	79.1	76.3	74.0
15% RWBM	96.7	93.8	77.0	74.7	76.5	74.2
$T_{0.05}$ Cal. value	16.82*		15.52*		19.40*	

1. Apparent retention (%) = $\frac{\text{nutrient content per g cooked food}}{\text{nutrient content per g raw food}} \times 100$

2. True retention (%) = $\frac{\text{nutrient content per g cooked food x g food after cooking}}{\text{nutrient content per g raw food x g food raw food}} \times 100$

3. differences between apparent and true retentions are compared by T-test,
* = significant at $T_{0.05}$ Calculated value $\geq$ 2.35 ($T_{0.05}$ Tabulated value)

two calculated methods were significant ($P \leq 0.05$) accordingto paired "T" tests. Conventional cooking had a lower retention value than did microwave cooking and could be attributed to the loss of nutrients by leaching into cooking water.

Table 6 shows the experimental and calculated mean values for insoluble, soluble and total dietary fiber of raw ingredients and dry pasta formulations. Both drum-dried bean meal and raw whole bean meal contained significantly higher dietary fiber content than durum wheat flour. After extrusion of dry pasta, the experimental value of total dietary fiber was slightly lower than the calculated value of total dietary fiber. For insoluble and soluble dietary fiber contents, experimental and calculated values were not significantly different.

The analysis of variance, mean values and Least Significant Difference (LSD) mean separation for dietary fiber of dry and cooked pasta are presented in Tables 7 and 8. Generally, cooking methods and pasta formulations resulted in significant differences for insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF). Pasta formulated with selected bean meals significantly increased total dietary and insoluble dietary fiber but did not resulted in significant differences for soluble dietary fiber. That is because the SDF was more readily loss than IDF during high temperature extrusion

Table 6. Comparison of dietary fiber[1] analysis mean values[2] in raw ingredients and extruded pre-cooked dry pasta formulated with selected bean meal (Experimental[3] vs Calculated[4])

Ingredients/ Formulations	IDF %		SDF %		TDF %	
	Exp	Cal	Exp	Cal	Exp	Cal
Ingredients						
Durum wheat	1.41	---	0.97	---	2.38.	---
Drum-dried bean meal	21.58	---	2.50	---	24.08	---
Raw whole bean meal	19.63	---	2.19	---	21.82	---
Dry Pasta Formulation						
Control pasta	0.99	1.41	0.81	0.97	1.80	2.38
15% DDBM pasta	3.58	4.44	1.39	1.20	4.97	5.62
25% DDBM pasta	6.22	6.45	1.22	1.35	7.44	7.81
15% RWBM pasta	3.95	4.14	1.19	1.15	5.14	5.30
$T_{0.05}$ Cal. value	2.77*		0.19		3.98*	

1. dietary fiber include: Insoluble Dietary Fiber (IDF); Soluble Dietary Fiber (SDF); and Total Dietary Fiber (TDF)
2. T-test, * = significant at $T_{0.05}$ Calculated value $\geq$ 2.35 ($T_{0.05}$ Tabulated value)
3. experimental protocol followed AACC (1983) analytical methods
4. calculated values were obtained for the following treatments: Control Pasta, 100% Durum Wheat; 15% DDBM pasta, 85% Durum wheat + 15% Drum-dried bean meal; 25% DDBM pasta, 75% Durum wheat + 15% Drum-dried bean meal; 15% RWBM pasta, 85% Durum wheat + 15% Raw whole bean meal

Table 7. Analysis of variance for dietary fiber[1] analysis of bean meal formulated pasta cooked by conventional and microwave energy

source of variation	df	IDF (%)	SDF (%)	TDF (%)
			Mean Squares[2]	
Main Effects				
Cooking[3]	2	5.16**	3.65**	10.94**
Formulation[4]	3	22.58**	0.49	29.50**
Interaction				
Cooking x Formulation	6	0.29	0.10	0.28
Error	11	0.41	0.15	0.63
% CV		14.28	22.51	12.87

1. dietary fiber include: Insoluble Dietary Fiber (IDF); Soluble Dietary Fiber (SDF); and Total Dietary Fiber (TDF)
2. n=3, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$
3. cooking treatments include: uncooked dry pasta; conventional cooking (100°C/2 mins); and microwave energy (740 Watts/5 mins)
4. formulations include: 100% durum wheat semolina; 15% drum-dried bean meal; 25% drum-dried bean meal; 15% raw whole bean meal

Table 8. Mean values[1] of dietary fiber[2] analysis for pasta formulated with selected bean meals and cooked by conventional and microwave energy

Cooked method/ formulation[3]	IDF (%)	SDF (%)	TDF (%)
Dry Pasta (Uncooked)			
Control	0.99c	0.81a	1.80c
15% DDBM	3.58b	1.39a	4.97b
25% DDBM	6.22a	1.22a	7.44a
15% RWBM	3.95b	1.19a	5.14b
Conventional cooked pasta			
Control	2.89c	0.95b	3.84c
15% DDBM	5.05b	1.66ab	6.71b
25% DDBM	7.86a	2.03a	9.89a
15% RWBM	5.37b	1.35ab	6.72b
Microwave cooked pasta			
Control	2.11b	2.31a	4.42c
15% DDBM	4.85a	2.29a	7.14b
25% DDBM	6.11a	2.88a	8.99a
15% RWBM	4.83a	2.35a	7.18b

1. n=2, Least significant difference ($LSD_{0.05}$) mean separation; means followed by unlike letters are significantly different at $p \leq 0.05$ within cooking method (column)
2. dietary fiber including Insoluble Dietary Fiber (IDF), Soluble Dietary Fiber (SDF), and Total Dietary Fiber (TDF)
3. pasta (pasta:water = 1:10) cooked by conventional (100°C/2 mins) and microwave energy (740 Watts/5 mins) for the following formulations: Control, 100% durum wheat; DDBM, drum-dried bean meal at 15 and 25% substitution; RWBM, raw whole bean meal at 15% substitution

process. Following conventional and microwave cooking, both soluble and insoluble dietary fiber content of pasta formulations were increased on a dry weight basis. These results are likely due to the loss of soluble carbohydrates during cooking that increased the concentration of dietary fiber in cooked pasta formulations.

Another important nutritional evaluation for legume supplemented pasta of concern is protein digestibility. The protein digestibility for raw ingredients, dry pasta formulations and cooked pasta formulations are summarized in Figure 15. For raw ingredients, the highest protein digestibility was for durum wheat semolina (90.7%), an intermediate level was obtained for drum-dried bean meal (86.5%), and the lowest level was for raw whole bean meal (75.5%). The relatively low protein digestibility for legumes was attributed to the stereo chemical resistance of globulins or to the presence of antinutritional factors, such as trypsin inhibitors, phytate and polyphenols (Walker and Kochhar, 1983; Tan et al., 1984; and Knuckles et al., 1985). However, the protease inhibitors were expected to be of limited influence due to heat treatment. All extruded pasta formulations had higher digestibility than raw ingredients. Previous investigators (Marquez and Lajolo, 1981; Akinyele, 1987) reported the improvement of protein digestibility by heat treatment or extrusion as a result of the destruction of trypsin inhibitors. Phillips and Baker

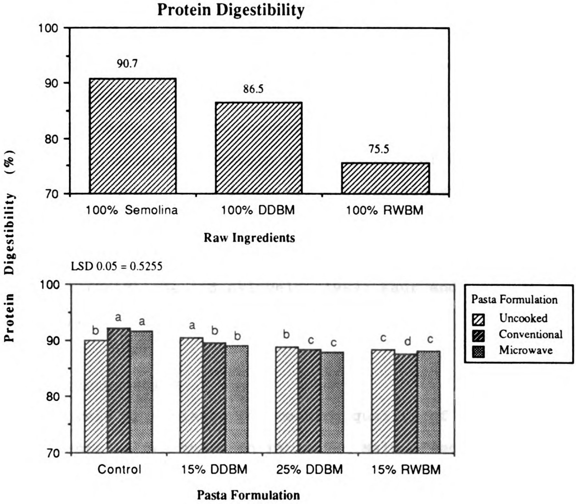


Figure 15. Top graph shows protein digestibility for raw ingredients (durum wheat semolina, drum-dried bean meal, and raw whole bean meal); Bottom graph shows protein digestibility for pasta formulations with uncooked, conventional and microwave cooked, unlike letters are different at $p \leq 0.05$ within cooking methods

(1987) also reported that in vitro protein digestibility for processed cowpeas had the highest value for extruded flour, and then steamed, drum-dried paste, and the lowest for raw meal.

Following conventional and microwave cooking, protein digestibility increased slightly for control pasta (100% semolina). In contrast, both conventional and microwave cooking slightly decreased protein digestibility of bean meal formulated pasta. The decreased protein digestibility after longer heating time may be due to the decrease of soluble protein and change the protein concentration in the pasta samples (Onigbinde and Akinyele, 1989; Kaur and Kapoor, 1990).

Physical characteristics

The analysis of variance for cooking quality of formulated pasta is presented in Table 9. Main effects of both cooking methods and pasta formulations significantly effected the cooking quality measures including: 1) cooked weight, 2) cooking loss, and 3) cooked firmness. The two way interaction effect of cooking method and formulation for cooked weight and firmness were no significant differences except for cooking loss was significantly different. Figure 16 shows the mean values for weight of formulated pasta cooked by conventional and microwave energy. Pasta supplemented with more drum-dried bean meal absorbed more

Table 9. Analysis of variance for cooked quality of bean meal formulated pasta cooked by conventional and microwave energy

source of variation	df	Cooked weight (g)	Cooking loss (%)	Firmness (N/100g)
			Mean Squares[1]	
Total	39	18.15	0.80	12090.00
<u>Main effects</u>				
Cooking[2]	1	151.59**	24.04**	87385.10**
Formulations[3]	3	122.25**	0.39**	61503.98**
<u>Interaction</u>				
Cooking x Formulation	3	3.90	1.36**	11798.97
Error	28	6.15	0.05	4689.49
% CV		1.17	5.63	8.21

1. n=5, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$
2. cooking treatments include: conventional cooking (100°C/2 mins); and microwave energy (740 Watts/5 mins)
3. formulations include: 100% durum wheat semolina; 15% drum-dried bean meal; 25% drum-dried bean meal; 15% raw whole bean meal

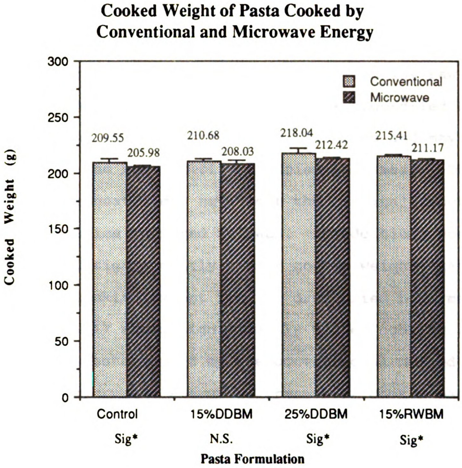


Figure 16. Mean values (n=5, standard deviation noted with vertical bar) of cooked weight (initial weight of 100g dry pasta/1000ml water) for formulated pasta: control (100% durum wheat semolina); drum-dried bean meal (15% and 25% substitution); raw whole bean meal (15% substitution) cooked by conventional (100°C/2 mins) and microwave (740 Watts/5 mins) energy: Sig* means significant differences within cooking methods

water than control pasta for both cooking methods. This effect may be caused by the higher protein content with more polar amino acids which are primary sites of protein-water interaction and thus enhance water absorption (Sathe et al., 1984). Furthermore, pasta formulated with 15% raw whole bean meal absorbed more water than 15% drum-dried bean meal. That was due to the ingredient differences and may be related to the heating of drum-dried bean meal. DDBM which had been preheated may have lost the original functional characteristics compared to RWBM. In addition, conventional cooking had significantly higher cooked weight than microwave cooking except for 15% drum-dried bean meal pasta.

Figure 17 shows significantly higher cooking loss of formulated pasta cooked by the conventional method than that cooked by microwave energy. Firmness of cooked pasta formulation is presented in Figure 18. Generally, firmness decreased with an increasing level of bean meal supplemented into the pasta. Moreover, conventional cooking had higher firmness values than that of microwave cooking.

Further analyses of pasta formulations texture data as it relates to cooked weight for conventional and microwave cooking are presented in Figures 19 and 20. For both cooking methods, cooked weight was inverse to cooked firmness. Increases in the supplemented level of drum-dried bean meal or raw whole bean meal pasta products caused increased cooked weight and decreased cooked firmness except

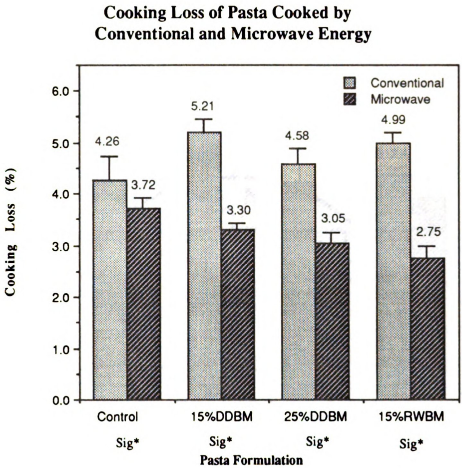


Figure 17. Mean values (n=5, standard deviation noted with vertical bar) of cooking loss (initial weight of 100g dry pasta/1000ml water) for formulated pasta: control (100% durum wheat semolina); drum-dried bean meal (15% and 25% substitution); raw whole bean meal (15% substitution) cooked by conventional (100°C/2 mins) and microwave (740 Watts/5 mins) energy: Sig* means significant differences within cooking methods

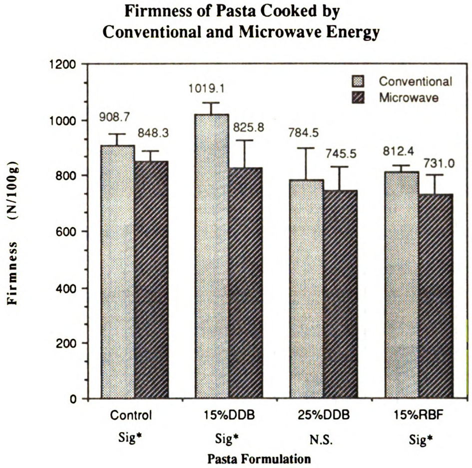


Figure 18. Mean values (n=5, standard deviation noted with vertical bar) of cooked firmness (initial weight of 100g dry pasta/1000ml water) for formulated pasta: control (100% durum wheat semolina); drum-dried bean meal (15% and 25% substitution); raw whole bean meal (15% substitution) cooked by conventional (100°C/2 mins) and microwave (740 Watts/5 mins) energy: Sig* means significant differences within cooking methods

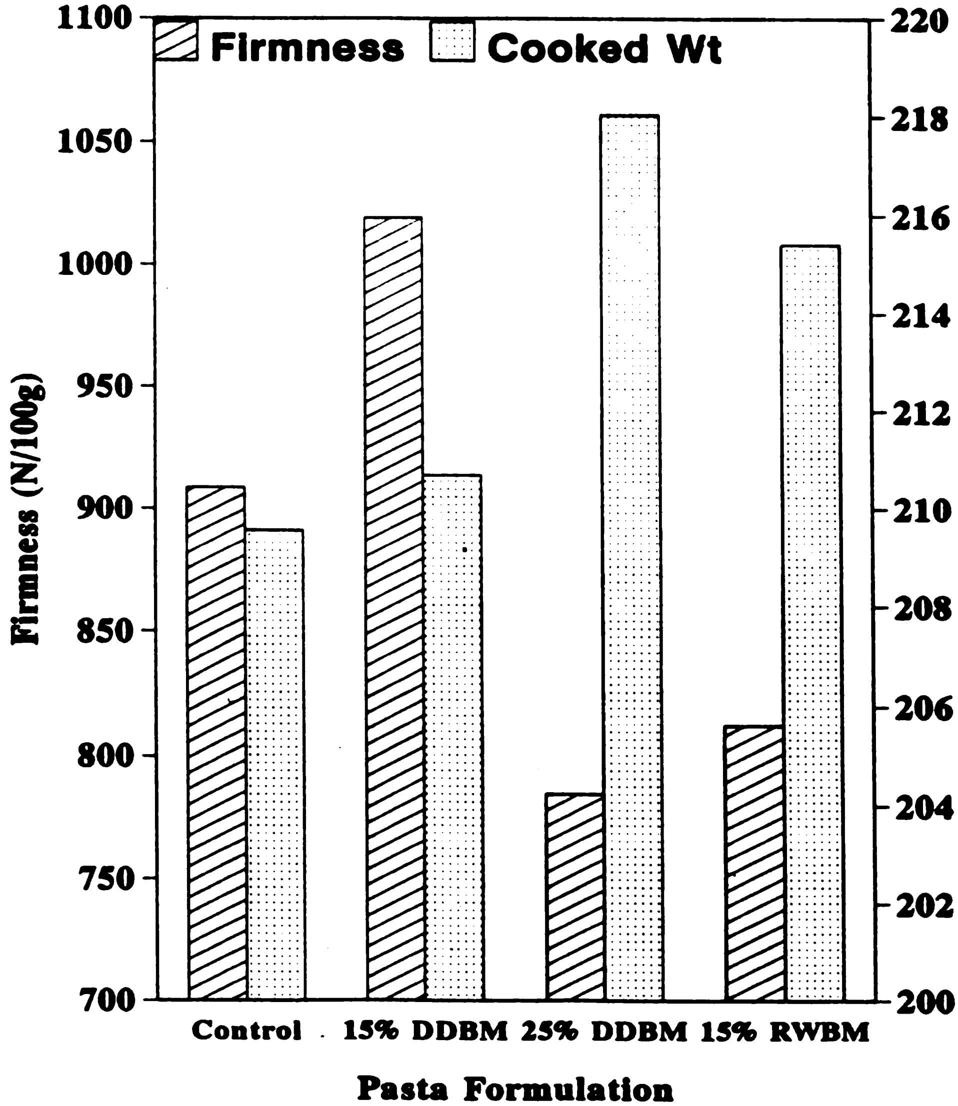


Figure 19. Relationship of formulated pasta firmness and cooked weight by conventional cooking

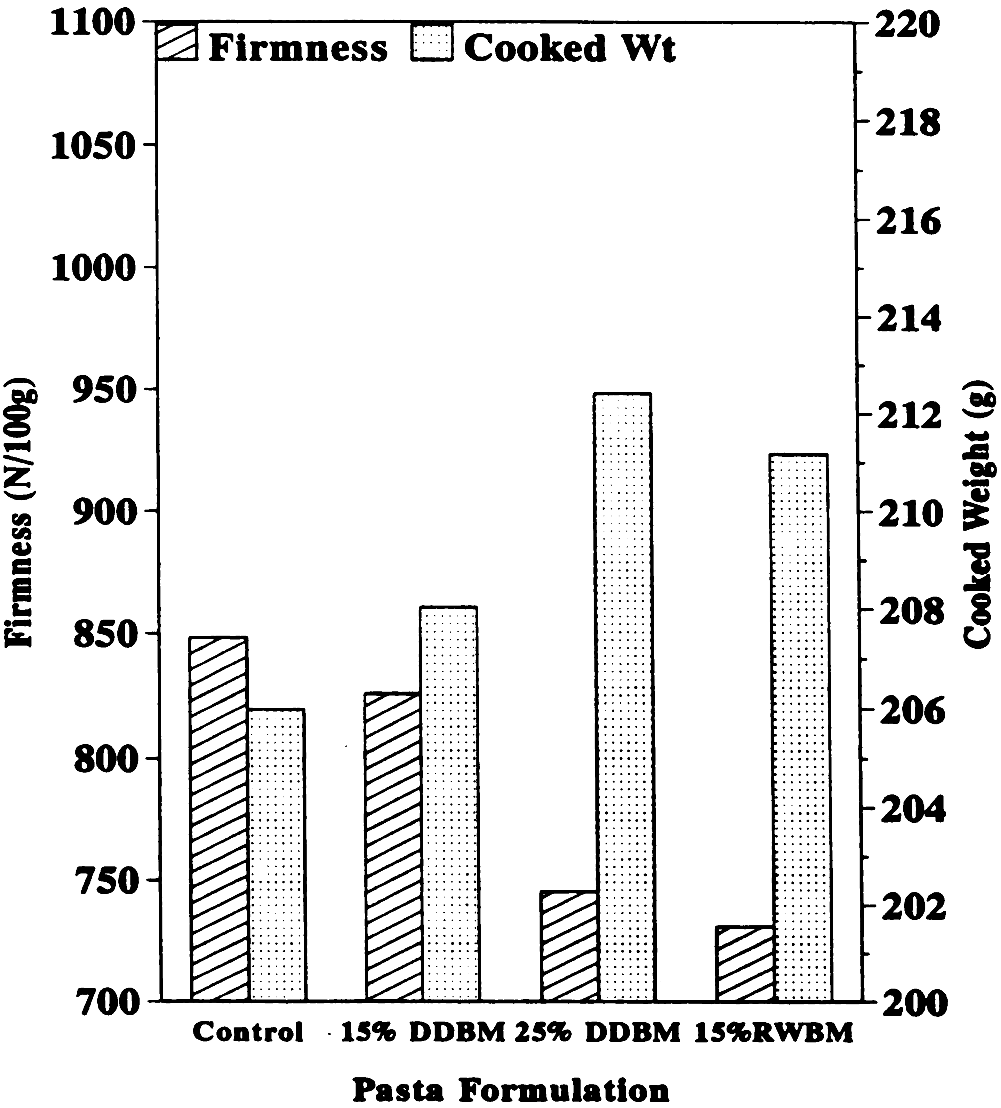


Figure 20. Relationship of formulated pasta firmness and cooked weight by microwave cooking

15% drum-dried bean meal heated by conventional energy. The firmness value decreased dramatically for 25% drum-dried bean meal pasta and the value was very similar to the firmness value of 15% raw whole bean meal pasta. Since all pasta formulations had been extruded cooked, preparation cooking is primarily the method to rehydrate the dry pasta. Pasta formulated with increased bean meal levels formed a better protein network with greater polar amino acids sites which attracted and bond more water molecules in the matrix. The protein matrix also promoted a more rapid water absorption at the initiation of cooking (Pagani et al., 1986).

Figure 21 shows the linear relationship for pasta formulations heated by conventional and microwave energy. Microwave cooking had significantly lower cooking firmness than conventional cooking for the same cooked weight. These results may be due to the microwave energy having a greater influence on the pasta structure than that of conventional energy. These may be caused by the microwave energy disruption of disulfide bonds in the pasta protein matrix which decreased firmness even though cooked weight is similar or lower.

The mean values for surface color of dry pasta formulations and cooked pasta formulations are presented in Table 10. The color for cooked pasta (including conventional and microwave cooking) appeared less dark

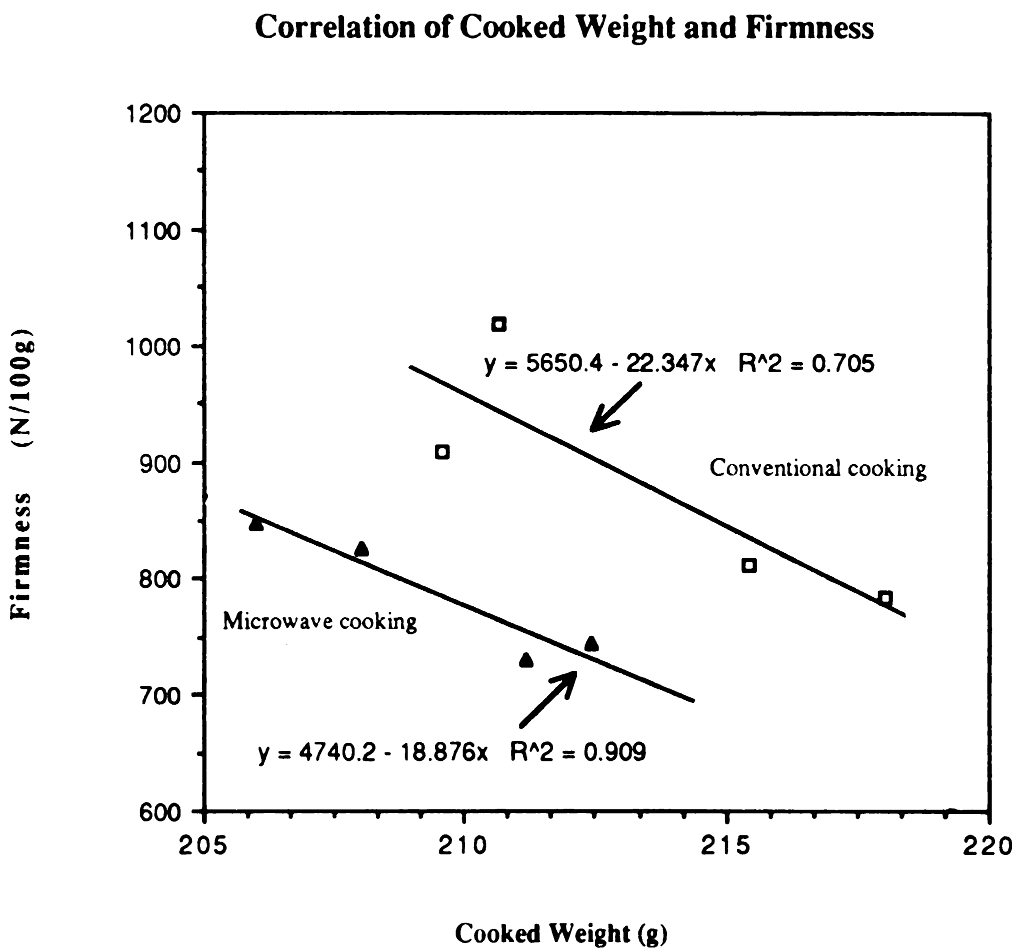


Figure 21. Linear relationship between cooked weight and cooked firmness for pasta formulated with selected bean meals heated by conventional and microwave energy

Table 10. Mean values[1] of surface color for dry and cooked (conventional[2] and microwave[3] energy) pasta formulated with selected bean meals

				COOKING METHOD					
	Uncooked Dry Pasta			Conventional			Microwave		
Formulation[4]	L	a	b	L	a	b	L	a	b
Control	59.6a	-0.4d	29.1a	68.4a	-3.3d	24.2a	69.2a	-3.0d	23.7a
15% DDBM	59.0bc	1.2b	27.9b	67.4b	-1.7b	23.2b	67.8b	-1.6b	22.9b
25% DDBM	58.7c	1.8a	27.0c	67.7b	-1.2a	22.3d	67.4b	-0.8a	21.8c
15% RWBM	59.4ab	0.6c	27.9b	68.7a	-2.1c	22.8c	69.0a	-2.2c	22.8b

1. n=5, least significant difference ($LSD_{0.05}$) mean seperation; means followed by unlike letters are significantly different within formulations (column)
2. conventional cooking: 100g dry pasta in 1000 ml boiling water for 2 minutes
3. microwave cooking (740 Watts): 100g dry pasta in 1000 ml cold water for 5 minutes
4. formulations include: 100% durum wheat samolina; drum-dried bean meal (15% and 25% substitution); raw whole bean meal (15% substitution)

(increase L), less red (decrease a_L), and less yellow (decrease b_L) than dry pasta. Formulated pasta prepared with more drum-dried bean meal had significantly darker, more red and less yellow color.

Sensory Evaluation of Bean Meal Supplemented Pasta

The analysis of variance for all sensory attributes is presented in Table 11. Mean squares of all main effects showed significant differences for all attributes except for the cooking methods for the smoothness attribute. Mean values for each sensory attribute score are presented in Table 12 with Least Significant Difference (LSD) mean separation reported within cooking methods. The chewiness of conventional cooked pasta was the only parameter that panelists detected not to be significantly different among pasta formulations. Significant differences among formulations for all the other remaining parameters were detected.

Graphical representations of the QDA results for conventional cooking and microwave cooking are presented in Figures 22 and 23, respectively. Comparing these two graphs, indicate that panelists found more differences for microwave cooking than for conventional cooking. Pasta formulated with drum-dried bean meal showed more grainy properties than 100% semolina control pasta. This may be due to physical properties of the two doughs. The drum-

Table 11. Analysis of variance for sensory evaluation of bean meal formulated pasta cooked by conventional and microwave energy

Source of variation	df	Visual			Texture		Taste
		Yellowiness	Shininess	Smoothness	Firmness	Chewiness	Flavor
		Mean Squares[1]					
Main Effects							
Cooking[2] (Cook.)	1	56.16**	9.36**	0.09	28.41**	45.38**	30.56**
Formulation[3] (Forml.)	3	30.32**	5.18**	63.22**	18.37**	7.81*	84.72**
Panelist (Panel.)	6	13.38**	12.96**	15.65**	10.60**	6.11*	11.58**
Interaction (a)							
Cook. x Forml.	3	28.47**	0.09	0.37	5.03*	2.08	38.67**
Cook. x Panel.	6	18.70**	9.77**	8.76**	10.69**	9.88**	19.08**
Forml. x Panel.	18	1.69*	1.69*	2.66*	1.56	3.14	4.13*
Interaction (b)							
Cook. x Forml. x Panel.	18	1.96*	1.09	3.42**	2.52	2.49	3.59*
Error	110	1.14	0.86	1.49	1.92	2.21	2.13
% CV		23.26	26.84	21.12	36.40	38.59	25.69

1. n=3, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$
2. cooking treatments include: conventional cooking (100°C/2 mins); and microwave energy (740 Watts/5 mins)
3. formulations include: 100% durum wheat semolina; 15% drum-dried bean meal; 25% drum-dried bean meal; 15% raw whole bean meal

Table 12. Mean values[1] of sensory scores[2] of pasta formulated with selected bean meals and cooked by conventional and microwave energy

Cooking/ Formulation	Visual			Texture		Taste
	Yellowiness	Shininess	Smoothness	Firmness	Chewiness	Flavor
Conventional Cooking (100°C/2 mins)						
Control (100% Semolina)	3.83±1.06b	4.25±1.37a	3.91±1.22c	3.25±1.21a	3.25±1.19a	5.83±1.34b
15% DDBM	4.67±1.20a	4.13±1.24a	6.51±0.88b	3.85±1.17a	3.62±0.85a	5.94±1.43b
25% DDBM	3.68±1.21b	3.30±1.09b	7.07±0.90a	2.58±0.99b	2.73±0.83a	7.02±1.15a
15% RWBM	4.01±1.55ab	3.88±1.05a	5.52±1.00b	3.31±1.13a	3.46±0.32a	6.73±1.39ab
Microwave Cooking (740 Watts/5 mins)						
Control (100% Semolina)	3.26±1.02d	3.66±0.98a	4.56±1.35d	3.96±0.74b	4.32±0.58ab	2.15±0.76c
15% DDBM	5.74±1.06b	3.32b1.21ab	6.28±1.18b	5.40±1.91a	4.87±1.95a	5.60±1.70b
25% DDBM	6.67±1.53a	2.98±0.72b	6.75±1.34a	4.39±1.05b	4.23±1.27b	7.42±1.57a
15% RWBM	4.68±1.16c	3.14±0.92ab	5.35±1.40c	3.84±0.84b	3.87±1.13b	5.86±2.03b

1. n=3, 7 trained panelists, Least significant difference mean separation, unlike letters are significant differences within each formulation at $p \leq 0.05$
2. scale for all characteristics: 0 = least; 10 = most

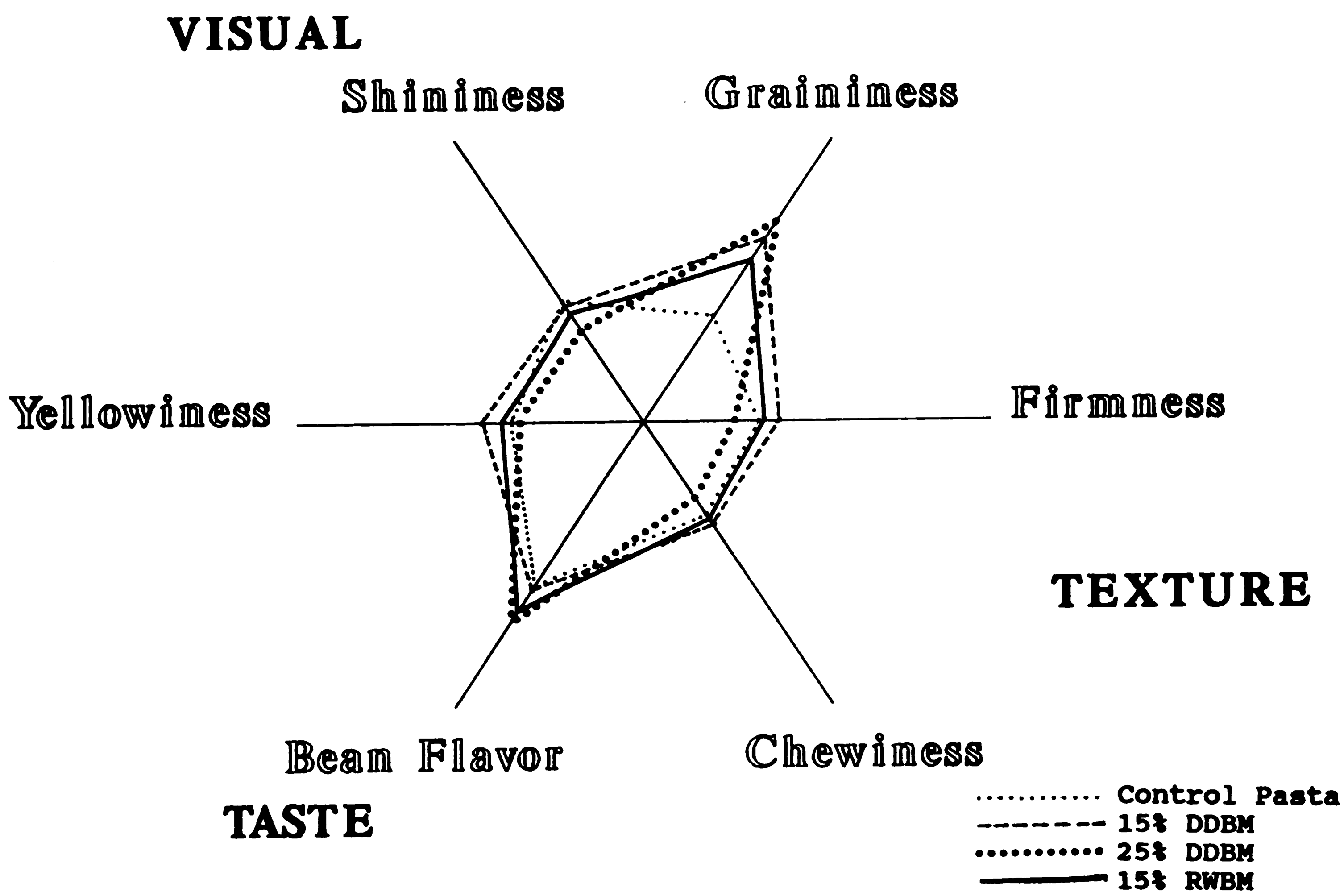


Figure 22. The Quantitative Descriptive Analysis (QDA) diagram of sensory evaluation for conventional cooking of bean meal formulated pastas

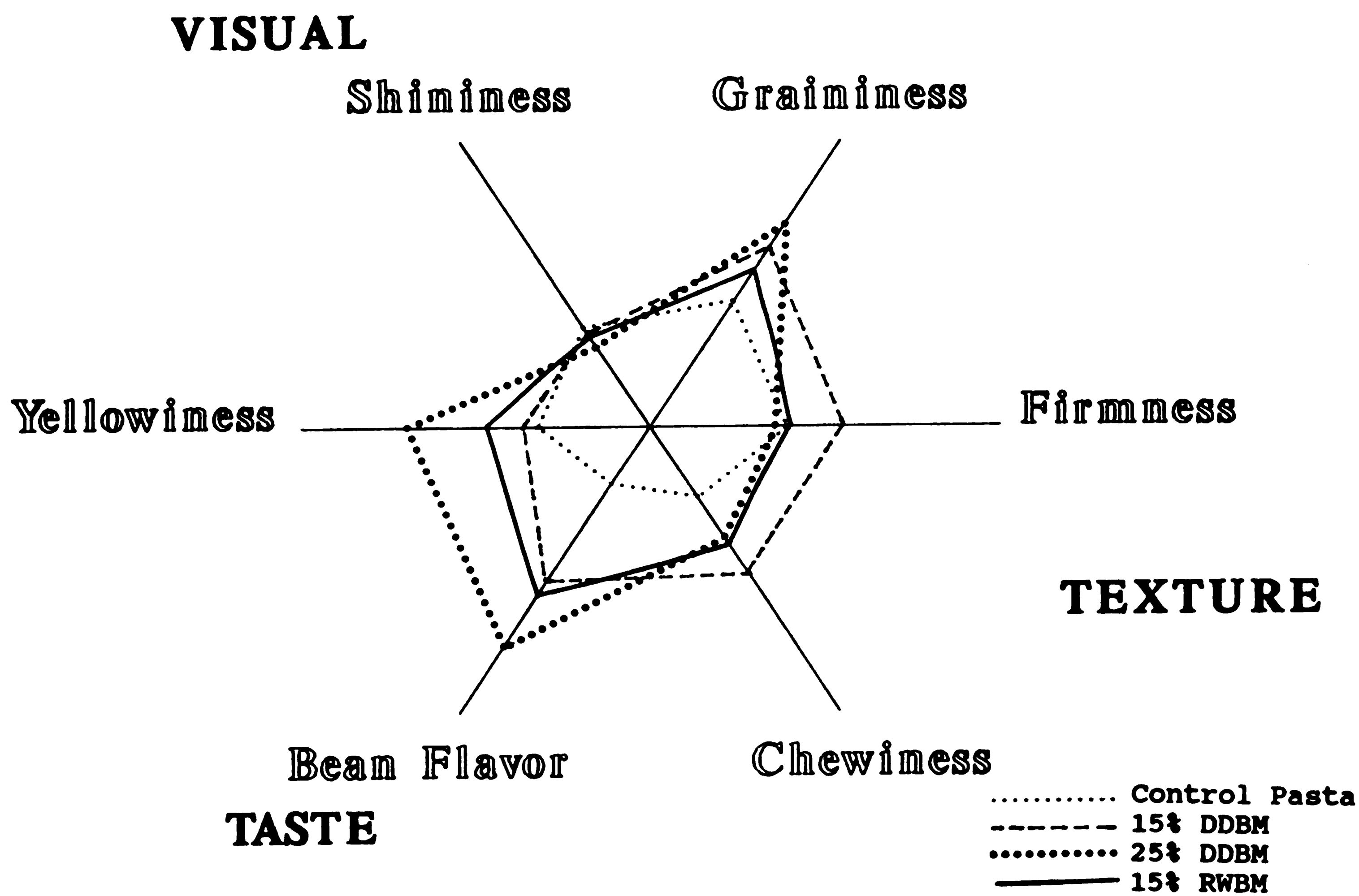


Figure 23. The Quantitative Descriptive Analysis (QDA) diagram of sensory evaluation for microwave cooking of bean meal formulated pastas

dried bean meal may not have mixed smoothly with wheat flourto form a uniform dough. Since the drum-dried bean meal had been pretreated with heat, most protein has been denatured and starch has been gelatinized which reduced their original functionality. For conventional cooking, pasta formulated with 15% raw whole bean meal had the least firmness and the least chewiness, while pasta formulated with 15% drum-dried bean meal had the highest firmness and the highest chewiness values. Similar results were observed for microwave cooking except that the least chewiness was shown for the control pasta.

For the yellowiness and bean flavor attributes, microwave cooking had higher scores than conventional cooking. These responses may be caused by microwave cooking retaining more pigments and flavors in cooked pasta than conventional cooking. It also means that water heated by conventional energy had greater extractive effects than that shown microwave energy. Figure 24 (a, b, c, d) demonstrate the perceived differences by the panelists for the two cooking methods and pasta formulated with 100% semolina, 15% and 25% drum-dried bean meal, and 15% raw whole bean meal.

Effect of Storage Conditions on the Cooking Properties of Bean Meal Formulated Pasta

Equilibrium moisture content

Figure 25 illustrates the water sorption isotherms of pasta formulated with drum-dried bean meal and raw whole

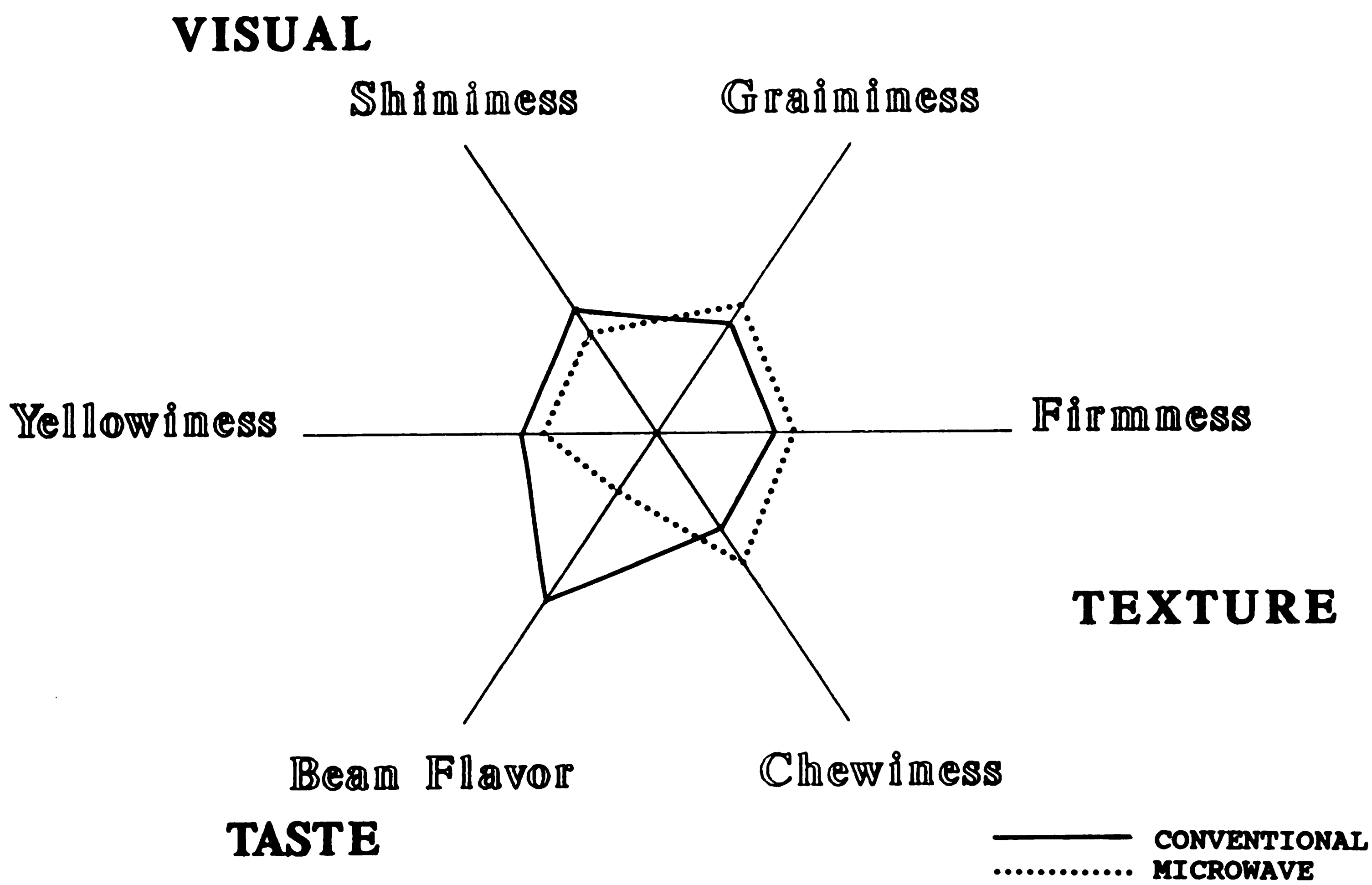


Figure 24a. QDA representation of panelist means for two cooking method for control pasta (100% durum wheat semolina)

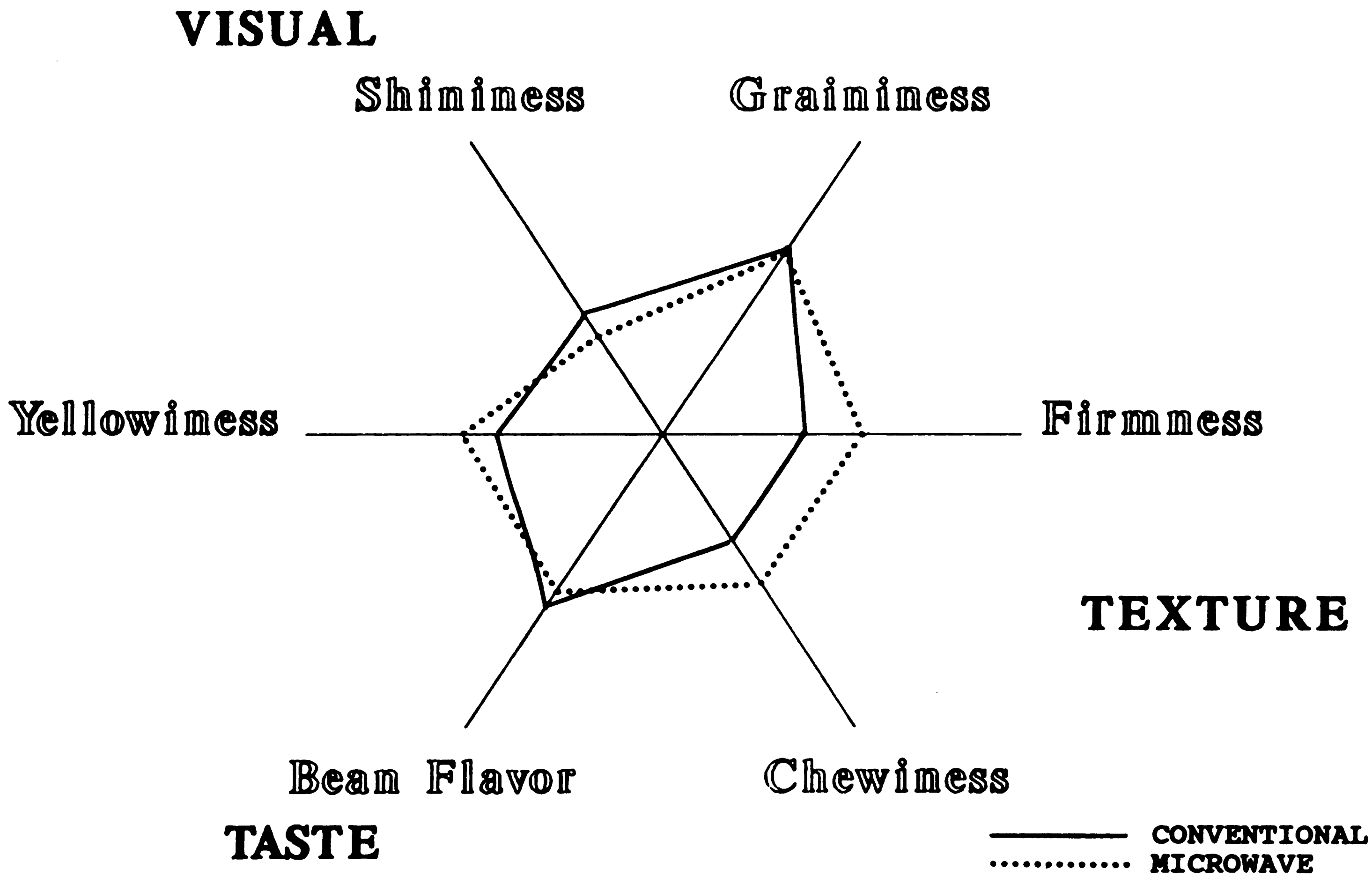


Figure 24b. QDA representation of panelist means for two cooking method for formulated pasta (15% drum-dried bean meal)

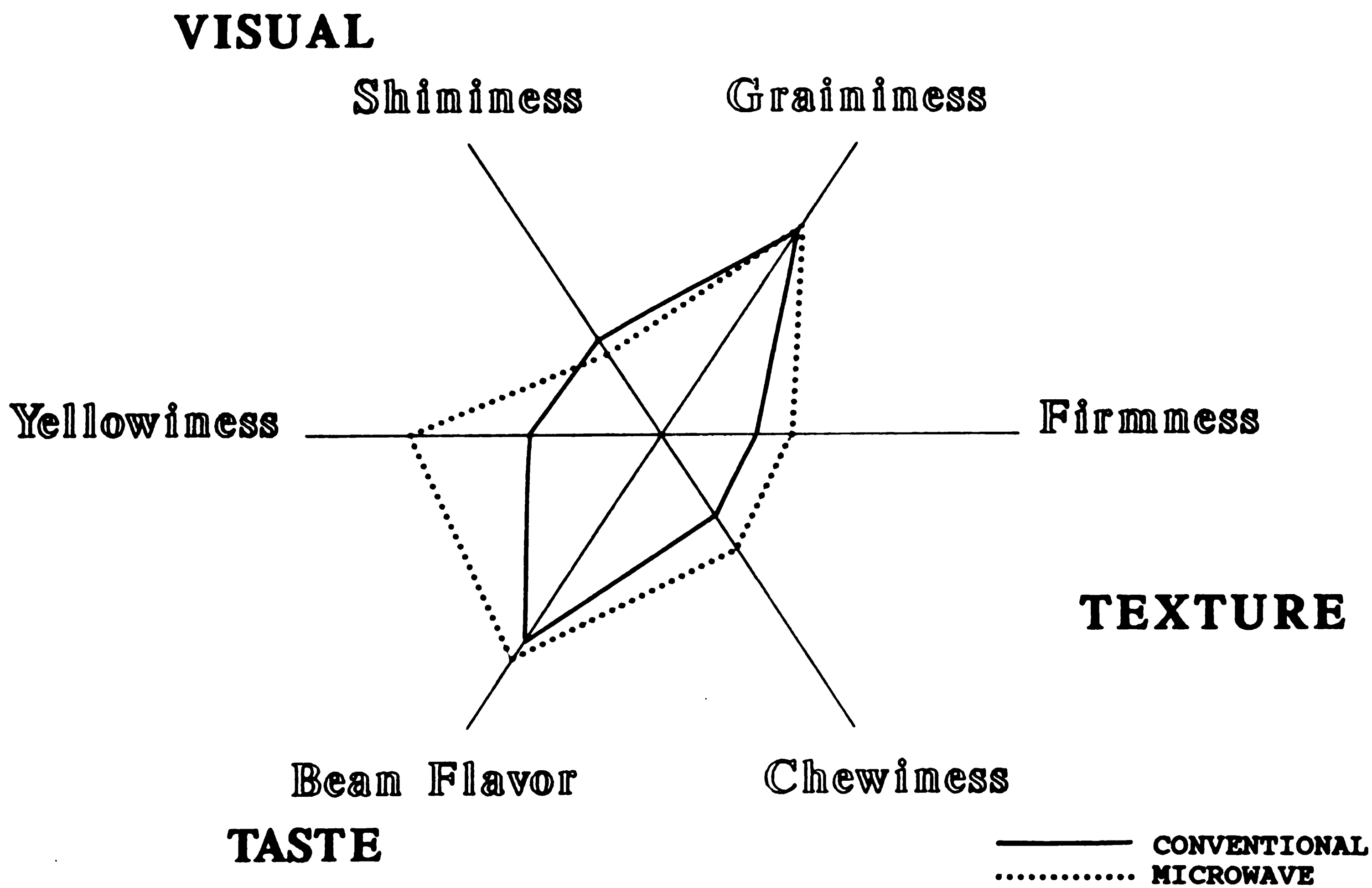


Figure 24c. QDA representation of panelist means for two cooking method for formulated pasta (25% drum-dried bean meal)

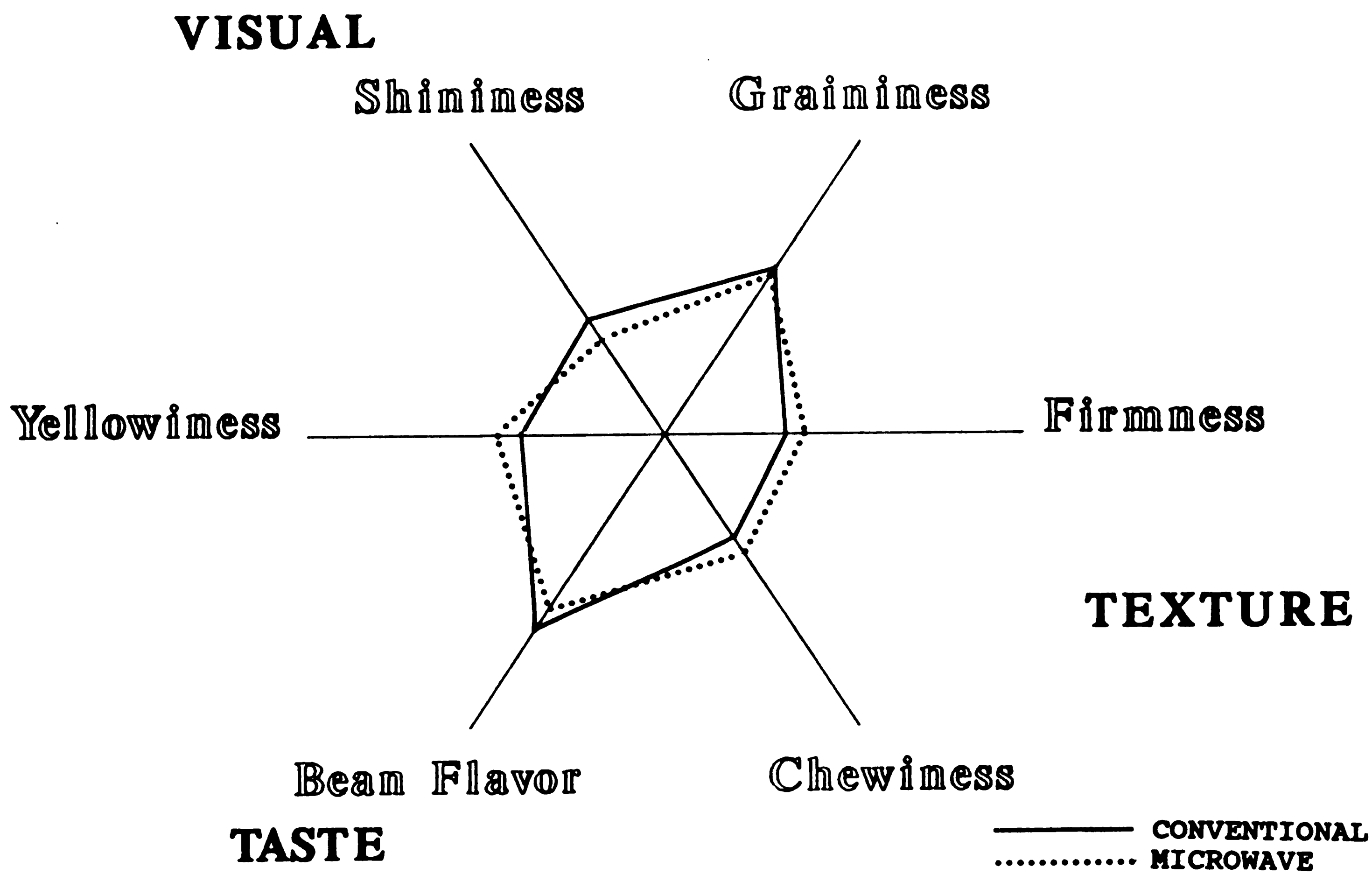


Figure 24d. QDA representation of panelist means for two cooking method for formulated pasta (15% raw whole bean meal)

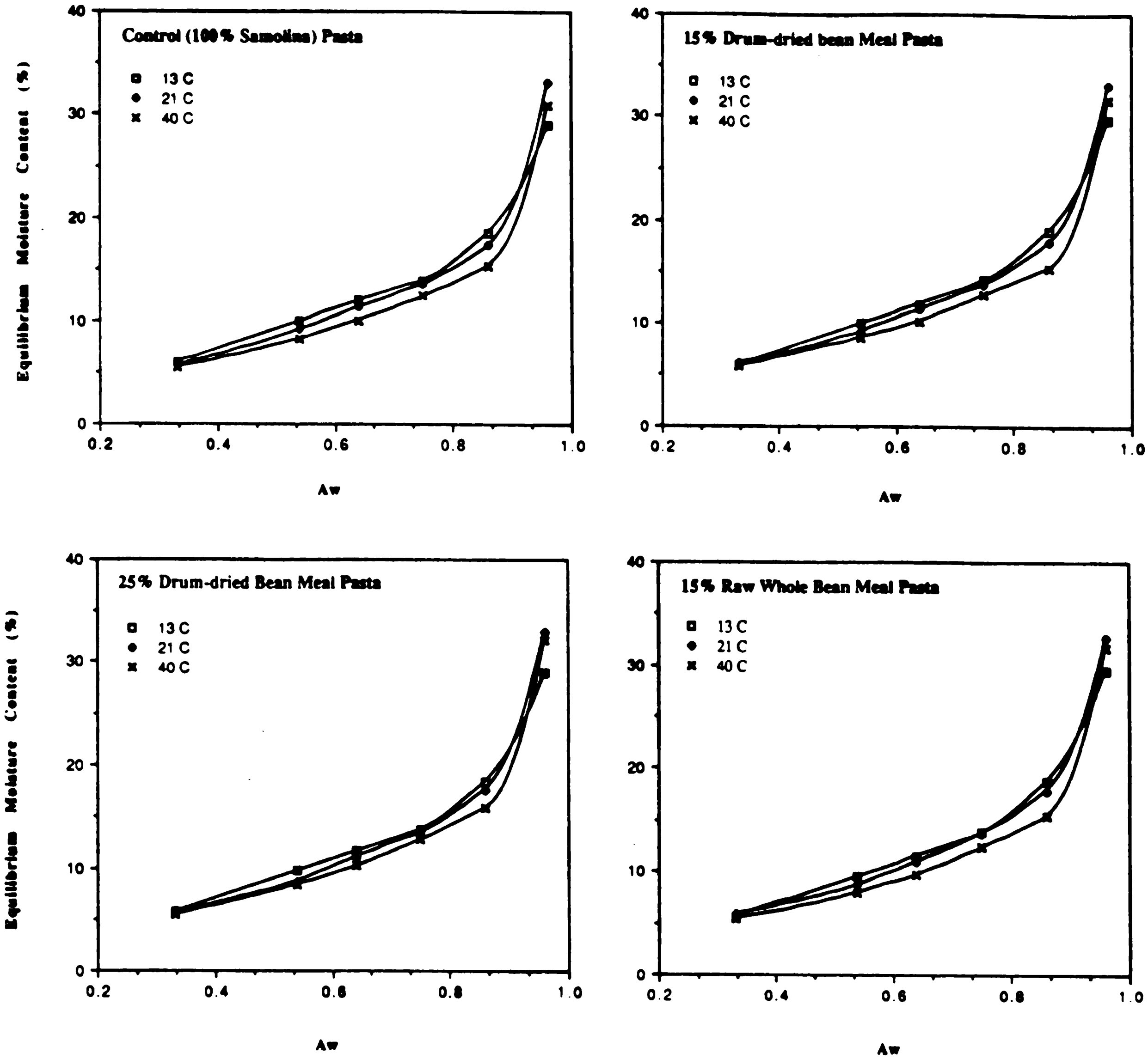


Figure 25. water sorption isotherms of pasta formulated with bean meals (100% durum wheat semolina, 15% and 25% drum-dried bean meal and 15% raw whole bean meal) storage at 13°C, 21°C, and 40°C

bean meal measured under three storage temperatures (13°C, 21°C, and 40°C). All pasta formulated with selected bean meals had similar sorption isotherm curve patterns. Bean meal levels of formulated pasta did not affect the equilibrium moisture content. Storage temperature influenced equilibrium moisture content. Higher storage temperature had lower equilibrium moisture content than low storage temperature when Aw < 0.86. However, when Aw > 0.9, low storage temperature (13°C) inversed to a lower equilibrium moisture content than that obtained at high storage temperature (21°C and 40°C). These results may be caused by the pregelatinization of starch which changed the structural properties and effected the equilibrium moisture content in dry pasta and promoted the absorption of more water under high storage temperature (Resmini and pagani, 1983).

Cooking Properties

The analysis of variance for the surface color of pasta formulations stored three months under three temperatures and relative humidities is presented in Table 13. Mean squares from the analysis of variance for dry pasta, conventional and microwave cooked pasta showed significant differences among temperatures, relative humidities and formulations. The mean values of surface color for dry and cooked pasta stored three months are presented in Tables 14, 15, 16 and 17. It was observed that high storage

Table 13. Analysis of variance of surface color of dry and cooked (conventional and Microwave) pasta formulated with selected bean meals storage under three temperatures and relative humidities for three months

source of variation	df	Uncooked Dry Pasta			COOKING METHOD: Conventional			COOKING METHOD: Microwave		
		L	a	b	L	a	b	L	a	b
		Mean Squares[1]								
Main Effects										
Temperature (Temp.)	2	2.18**	14.50**	27.13**	43.19**	20.79**	18.98**	72.87**	19.59**	10.78**
% RH	2	12.92**	0.86**	1.78**	7.05**	0.48**	1.13**	7.21**	3.84**	0.46**
Formulation (Forml.)	3	66.70**	56.20**	15.10**	32.31**	30.99**	3.63**	38.18**	45.71**	6.67**
Interaction (a)										
Temp.x %RH	4	11.43**	5.99**	0.64**	5.40**	4.15**	0.63**	3.57**	5.54**	0.80**
Temp.x Forml.	6	1.70**	0.80**	1.48**	2.49**	0.37**	3.14**	0.98**	0.96**	2.18**
%RH x Forml.	6	5.62**	0.18**	0.06**	1.08**	0.34**	0.21**	0.96**	0.31**	0.15**
Interaction (b)										
Temp.x %RH x Forml.	12	0.90**	0.45**	0.16**	0.31**	0.24**	0.08**	0.67**	0.67**	0.15**
Error	105	0.09	0.02	0.02	0.10	0.04	0.03	0.09	0.07	0.03
% CV		0.51	18.67	0.50	0.47	-11.20	0.80	0.43	-18.34	0.82

1. n=4, ** = significant at $p \leq 0.01$

Table 14. Mean values[1] of surface color for dry and cooked (conventional[2] and microwave[3]) **100% durum wheat control pasta** stored under three temperatures and relative humidities for three months

Temp. (C)	%RH	Uncooked Dry Pasta			COOKING METHOD: Conventional			COOKING METHOD: Microwave		
		L	a	b	L	a	b	L	a	b
13	56%	60.0	-0.8	28.9	69.7	-3.4	23.6	67.9	-2.0	23.2
	75%	61.1	-0.8	28.7	69.4	-3.2	23.1	69.1	-2.4	23.2
	86%	60.9	-1.3	28.5	70.0	-3.5	22.8	69.8	-3.6	23.0
21	56%	59.5	-0.7	28.4	68.5	-2.9	23.3	68.5	-3.4	23.3
	75%	61.4	-1.0	28.5	70.5	-3.2	23.0	70.0	-3.4	23.0
	86%	61.8	-1.1	28.3	70.1	-3.4	22.9	70.0	-3.4	23.0
40	56%	60.6	-0.8	26.4	68.3	-2.5	20.8	65.5	-2.3	21.1
	75%	62.5	-0.5	26.6	68.4	-2.5	21.1	67.6	-2.1	21.7
	86%	61.2	-0.5	26.3	69.4	-2.2	20.2	68.7	-2.4	20.9
$LSD_{0.05}$		0.4	0.2	0.2	0.5	0.3	0.3	0.4	0.4	0.3

1. n=2, least significant difference ($LSD_{0.05}$) mean seperation
2. conventional cooking: 100g dry pasta in 1000ml boiling water for 2 mins
3. microwave cooking (740 watts): 100g dry pasta in 1000ml cold water for 5 mins

Table 15. Mean values[1] of surface color for dry and cooked (conventional[2] and microwave[3]) **15% drum-dried bean meal formulated pasta** stored under three temperatures and relative humidities for three months

Temp. (C)	%RH	Uncooked Dry Pasta			COOKING METHOD: Conventional			COOKING METHOD: Microwave		
		L	a	b	L	a	b	L	a	b
13	56%	59.2	1.1	27.9	67.4	-0.5	22.5	67.6	-0.7	22.5
	75%	59.2	0.7	27.8	68.6	-1.2	22.4	68.6	-0.6	22.4
	86%	58.8	0.3	27.7	68.6	-1.2	22.2	68.4	-2.8	22.6
21	56%	58.2	1.0	27.4	67.5	-1.9	22.9	67.1	-1.5	22.5
	75%	60.2	0.6	27.7	69.0	-2.1	22.5	68.6	-1.7	22.4
	86%	60.1	0.5	27.6	69.5	-2.1	22.4	68.4	-1.9	22.5
40	56%	59.7	1.4	26.5	66.5	-1.1	21.8	65.8	-0.9	21.6
	75%	59.4	2.0	26.6	66.2	-0.6	21.9	66.1	-0.5	22.2
	86%	57.4	2.4	25.9	66.4	-0.2	21.3	66.6	-0.5	21.7
$LSD_{0.05}$		0.4	0.2	0.2	0.5	0.3	0.3	0.4	0.4	0.3

1. n=2, least significant difference ($LSD_{0.05}$) mean seperation
2. conventional cooking: 100g dry pasta in 1000ml boiling water for 2 mins
3. microwave cooking (740 watts): 100g dry pasta in 1000ml cold water for 5 mins

Table 16. Mean values[1] of surface color for dry and cooked (conventional[2] and microwave[3]) **25% drum-dried bean meal formulated pasta** stored under three temperatures and relative humidities for three months

Temp (C)	%RH	Uncooked Dry Pasta			COOKING METHOD: Conventional			COOKING METHOD: Microwave		
		L	a	b	L	a	b	L	a	b
13	56%	58.1	2.6	26.5	67.1	0.0	21.3	66.7	0.5	21.5
	75%	58.2	2.7	26.5	68.4	-1.5	21.9	68.2	-0.1	21.5
	86%	57.1	0.7	26.6	68.2	-1.1	21.9	68.4	-1.7	21.5
21	56%	57.7	1.7	26.5	67.5	-1.2	22.0	67.1	-0.7	21.7
	75%	58.5	1.7	26.8	68.5	-1.5	21.6	68.8	-1.1	21.4
	86%	58.0	1.7	26.5	68.5	-1.3	21.9	67.7	-1.0	21.8
40	56%	58.5	2.2	26.0	66.6	-0.4	21.3	65.3	0.4	21.3
	75%	57.7	3.1	26.2	65.5	0.3	21.4	65.3	0.8	21.7
	86%	55.1	3.7	24.9	65.3	0.6	21.1	64.5	1.2	21.0
$LSD_{0.05}$		0.4	0.2	0.2	0.5	0.3	0.3	0.4	0.4	0.3

1. n=2, least significant difference ($LSD_{0.05}$) mean seperation
2. conventional cooking: 100g dry pasta in 1000ml boiling water for 2 mins
3. microwave cooking (740 watts): 100g dry pasta in 1000ml cold water for 5 mins

Table 17. Mean values[1] of surface color for dry and cooked (conventional[2] and microwave[3]) **15% raw whole bean meal formulated pasta** stored under three temperatures and relative humidities for three months

Temp (C)	%RH	Uncooked Dry Pasta			COOKING METHOD: Conventional			COOKING METHOD: Microwave		
		L	a	b	L	a	b	L	a	b
13	56%	59.7	1.3	27.4	68.9	-1.3	22.3	68.7	-0.9	22.1
	75%	60.0	1.4	27.6	69.8	-1.6	22.3	69.5	-0.3	22.1
	86%	58.0	-0.3	27.3	70.2	-2.5	22.1	69.1	-2.7	22.6
21	56%	59.1	0.2	27.4	69.4	-2.8	22.3	68.8	-2.1	22.5
	75%	60.3	0.2	27.8	70.2	-2.6	22.4	69.9	-2.3	22.4
	86%	59.4	0.3	27.3	70.3	-2.5	22.2	69.5	-2.2	22.1
40	56%	61.2	0.6	27.0	69.0	-1.8	21.6	67.6	-1.3	22.1
	75%	59.1	1.6	26.8	67.9	-1.3	22.1	67.0	-0.9	22.1
	86%	57.5	2.1	26.1	67.7	-0.9	21.2	66.7	-0.5	21.4
$LSD_{0.05}$		0.4	0.2	0.2	0.5	0.3	0.3	0.4	0.4	0.3

1. n=2, least significant difference ($LSD_{0.05}$) mean seperation
2. conventional cooking: 100g dry pasta in 1000ml boiling water for 2 mins
3. microwave cooking (740 watts): 100g dry Pasta in 1000 ml cold water for 5 mins

temperatures and high relative humidities for 100% durum wheat control pasta showed lighter color (increased L value) and less yellow (decreased b value). These results may be due to the color degradation of the native durum wheat pigments. For pasta formulated with drum-dried bean meal and raw whole bean meal stored at higher temperature and high relative humidity showed darker color (decreased L value) and less yellow (decreased b value). Generally, cooked pasta was lighter, less red and less yellow than dry pasta. Cooked pasta color values between conventional and microwave cooking were very similar.

The surface color values for non-stored and stored pasta formulated with selected bean meals is presented in Table 18. It was observed that storage had greater effect on the color for control (100% semolina) pasta than the other pasta formulations. After three months storage, control pasta showed lighter, less red and less yellow appearance than non-stored control pasta. The color degradation may be due to the oxidation of carotenoids in durum wheat flour. However, the storage color changes were not significantly different among the other pasta formulations.

The analysis of variance for cooking quality of stored pasta formulations is presented in Table 19. The mean squares for cooked weight, cooking loss and cooked firmness showed significant differences among cooking methods,

Table 18. Mean values[1] of surface color for non-storage and storage[1] pasta formulated with selected bean meals

Pasta formulation[2]	Non-Stored pasta			Stored pasta		
	L	a	b	L	a	b
Control	59.6	-0.4	29.1	61.0	-0.8	27.8
15% DDBM	59.0	1.2	27.9	59.1	1.1	27.2
25% DDBM	58.7	1.8	27.0	57.7	2.2	26.3
15% RWBM	59.4	0.6	27.9	59.4	0.8	27.2

1. mean values for all storage conditions including three temperatures (13°C, 21°C, 40°C) and relative humidities (56% RH, 75% RH, 86% RH)
2. pasta formulations including: Control: 100% durum wheat semolina; DDBM: drum-dried bean meal; and RWBM: raw whole bean meal

Table 19. Analysis of variance for cooking quality of pasta formulated with bean meals cooked by conventional and microwave energy storage under three temperature and three relative humidities for three months

Source of variation	df	Cooked wt (g)	Cooking Loss (%)	Firmness (N/100g)
			Mean Squares[1]	
<u>Main Effect</u>				
Cooking[2] (Cook.)	1	763.79**	145.26**	303656.09**
Temperature (Temp.)	2	285.54**	10.57**	334042.51**
% RH	2	514.79**	0.11	17677.20**
Formulation[3] (Forml.)	3	599.24**	2.16**	230831.85**
<u>Interaction (a)</u>				
Cook. x Temp.	2	501.59**	0.10	132158.32**
Cook. x %RH	2	18.32*	2.54**	3302.07
Cook. x Forml.	3	74.15**	0.25**	42636.29**
Temp. x %RH	4	51.69**	0.42**	44493.02**
Temp. x Forml.	6	5.50	0.08	1959.55
%RH x Forml.	6	17.67**	0.19*	6152.87

Table . (Cont'd.)

Source of variation	df	Cooked wt	Cooking Loss	Firmness
Interaction (b)				
Cook. x Temp. x %RH	4	25.73**	2.57**	19788.25**
Cook. x Temp. x Forml.	6	7.07	0.29**	3621.23
Cook. x %RH x Forml.	6	4.37	0.19**	5011.36
Temp. x %RH x Forml.	12	8.34	0.09	5380.24
Interaction (c)				
Cook. x Temp. x %RH x Forml.	12	3.68	0.13*	4379.69
Error		4.99	0.06	3837.93
% CV		1.09	8.02	7.13

1. n=2, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$
2. cooking treatments include: conventional cooking (100°C/2 mins); and microwave energy (740 Watts/5 mins)
3. formulations include: 100% durum wheat semolina; 15% drum-dried bean meal; 25% drum-dried bean meal; 15% raw whole bean meal

storage temperatures, relative humidities and formulations, except relative humidities for cooking loss was not significantly different.

Figure 26 shows mean values of cooked weight for storage pasta formulations heated by conventional and microwave energy. For conventional heating, cooked weight of control pasta and 15% drum-dried bean meal pasta remained constant as the storage temperature increased under 56% RH, 75% RH and 86% RH. These results are similar to the data reported by Duszkiewixz-Reinhard et al. (1988) in which pasta fortified with 10% bean flour had lower cooked weight. The cooked weight of 25% drum-dried bean meal pasta was increased slightly as the storage temperature increased under 56% RH and 86% RH. This observation may be caused by the increased bean meal (increased protein content) which had greater water absorption by increased polar amino acids sites. However, it is important to note that not all of these sites may be available for such interaction due to conformational and steric constraints (Sathe et al. 1984). Generally, for microwave heating, cooked weight decreased as storage temperature increased under three relative humidities for all stored pasta formulations. Cooked weight for 25% drum-dried bean meal pasta increased slightly and then decreased at 40°C under 56% RH and 75% RH. Comparison of conventional and microwave cooking, higher relative humidities and higher storage temperatures had greater

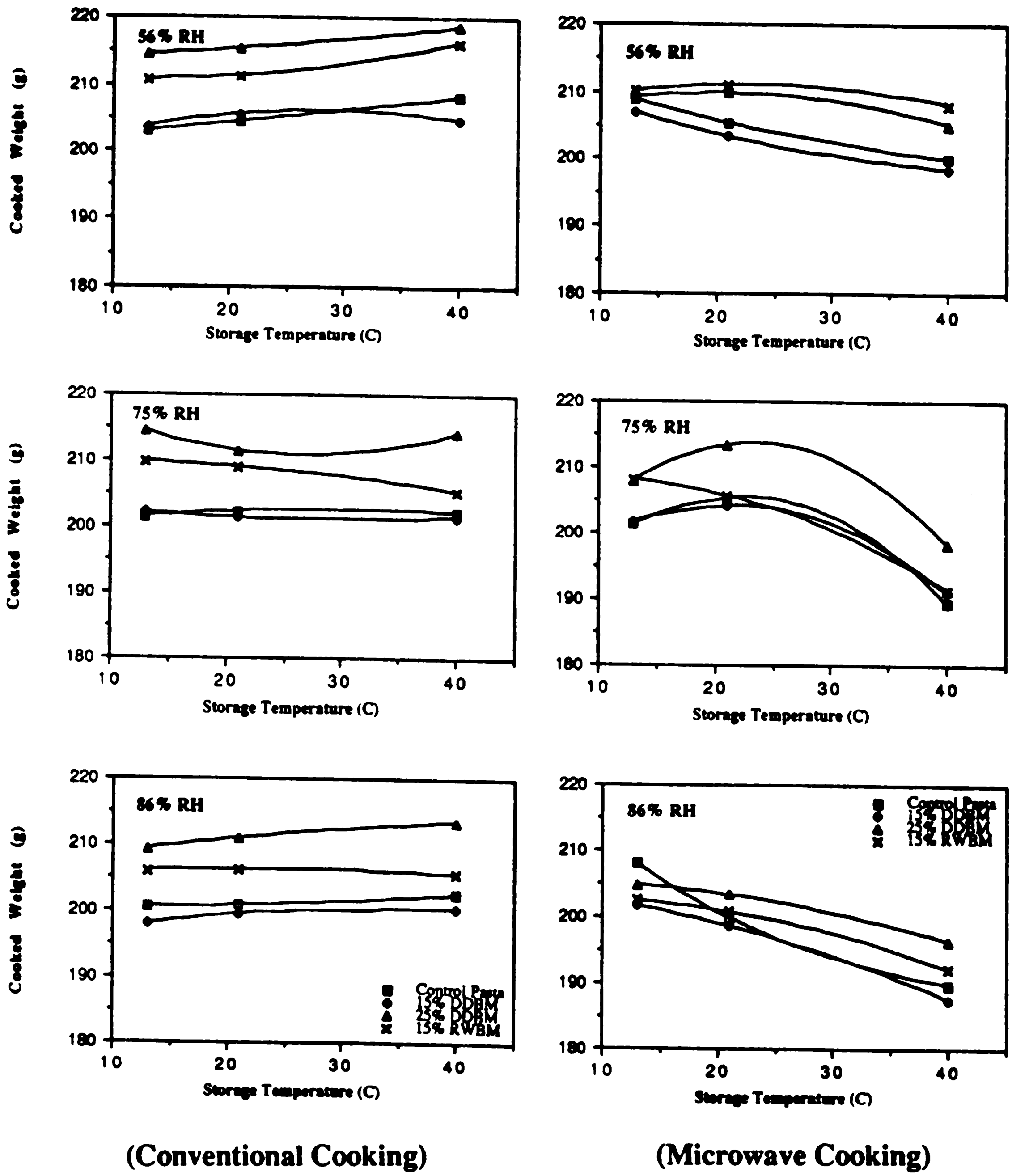


Figure 26. Cooked weight of pasta formulated with selected bean meals (Control (100% Semolina), 15% DDBM, 25% DDBM and 15% RWBM) storage at three temperatures (13°C, 21°C, 40°C) and three relative humidities (56%RH, 75%RH, 86%RH) for three months: conventional vs microwave energy

effect on microwave cooked weight. Since microwave heating can generate heat by the food itself or by conduction heat from the surrounding water condition (Klaus, 1976), high storage temperature and high relative humidity may effect the dry pasta internal water content and protein-water or carbohydrate-water interactions which will effect their cooking quality.

Mean values for cooking loss of storage pasta formulations heated by conventional and microwave energy are presented in Figure 27. For conventional cooking, cooking loss decreased during storage for three months at higher storage temperatures and higher relative humidities for all pasta formulations. Duszkiewicz-Reinhard et al. (1988) reported data that had this similar lower cooking loss after three months storage under the room temperature. These results may due to changes in the pasta structure during storage, particularly crosslinking and polymerization reactions, which increase binding of soluble constituents and decreased cooking loss. The microwave cooking loss decreased under low relative humidity (56% RH), while the cooking loss for 75% RH and 86% RH maintained constant for all pasta formulations. The change for cooking loss among different pasta formulations were very similar under the same storage temperature and relative humidity.

For microwave cooking, cooking loss decreased as the storage temperature increased under 56% RH for all pasta

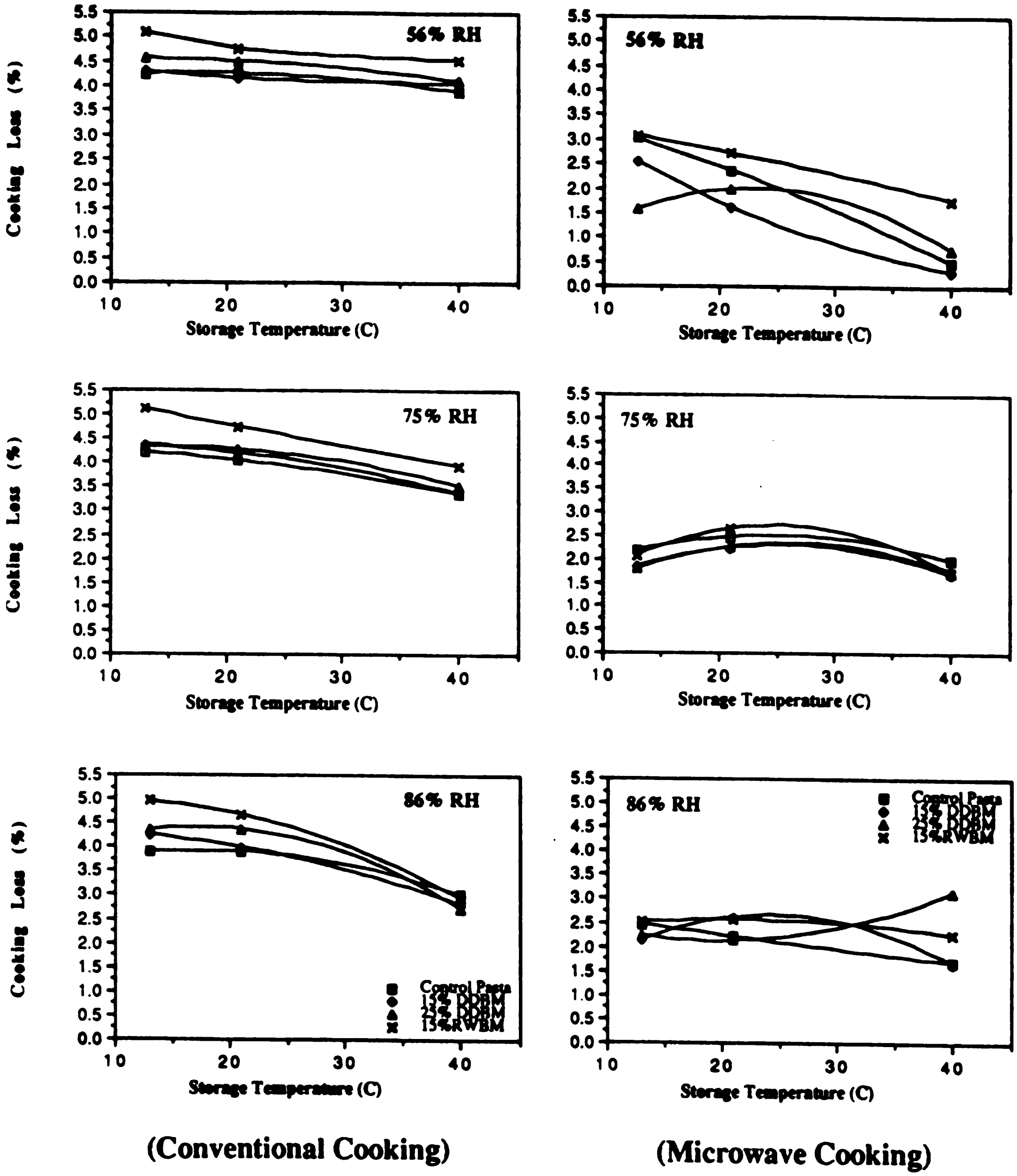


Figure 27. Cooking loss of pasta formulated with selected bean meals (Control (100% Semolina), 15% DDBM, 25% DDBM and 15% RWBM) storage at three temperatures (13°C, 21°C, 40°C) and three relative humidities (56%RH, 75%RH, 86%RH) for three months: conventional vs microwave energy

formulations, except for 25% drum-dried bean meal pasta stored at 21°C under 75% RH. Cooking loss for most pasta formulations maintained constant as storage temperature increased under 75% RH and 86% RH.

A comparison of conventional and microwave heating demonstrated that microwave cooking had lower cooking loss than conventional cooking. However, higher storage temperatures and higher relative humidities had greater effect on cooking loss of pasta prepared by conventional cooking. This effect may be caused by conventional cooking has a high initial temperature which increased leachate into cooking water. Further, mass action under boiling water acting may increase extraction rate.

The cooked firmness mean squares (Table 19) for formulated pasta showed highly significantly differences among all variables (cooking methods, storage temperatures, relative humidities, and formulations). Mean values for cooked firmness of pasta formulations heated by conventional and microwave energy are presented in Figure 28. The responses obtained for conventional cooking of pasta indicated that as the storage temperature and relative humidity increased, the cooked firmness also increased for all stored pasta formulations. In the contrast, the firmness of control pasta and 15% drum-dried bean meal pasta stored under 86% RH for three months slightly decreased at 21°C and then increased at 40°C. Under the same storage

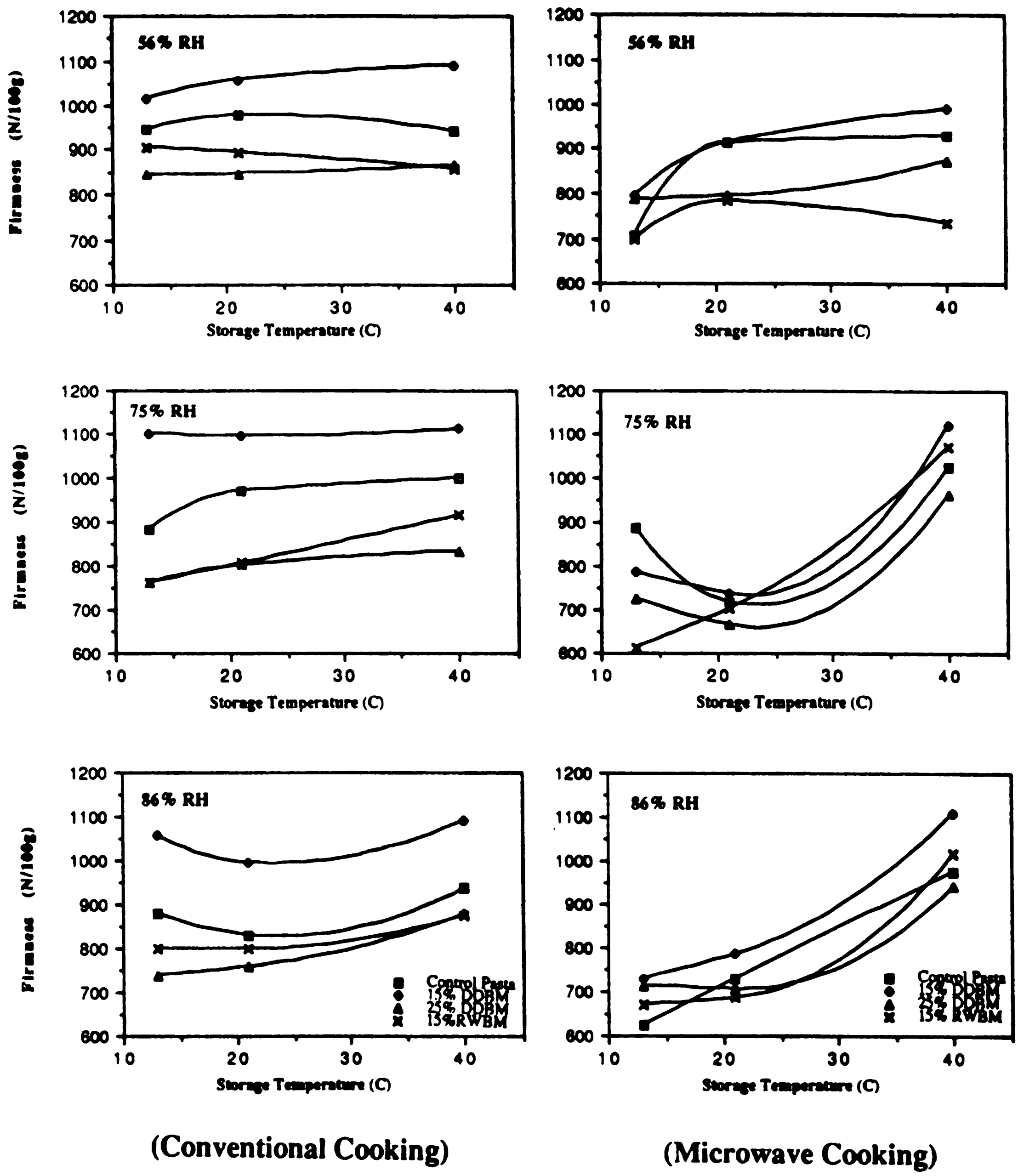


Figure 28. Cooked firmness of pasta formulated with selected bean meals (Control (100% Semolina), 15% DDBM, 25% DDBM and 15% RWBM) storage at three temperatures (13°C, 21°C, 40°C) and three relative humidities (56%RH, 75%RH, 86%RH) for three months: conventional vs microwave energy

relative humidity, 15% drum-dried bean meal pasta showed the greatest firmness and 15% raw whole bean meal had the least firmness. This may be due directly to the differences of protein and starch characteristics of ingredients.

Generally, for microwave cooked pasta, firmness increased as storage temperature increased under 56% RH, 75% RH and 86% RH for most pasta formulations. However, for all pasta formulations except 15% raw whole bean meal pasta, as storage temperature increased from 13°C to 21°C under 75% RH, the firmness was slightly decreased and then increased again when storage temperature changed from 21°C to 40°C.

Between these two cooking methods, conventionally cooked pasta was firmer than that obtained by microwave cooking. However, the higher temperature and higher relative humidity had a greater effect on microwave cooked firmness for most stored pasta formulations.

A further analysis for cooked weight, cooking loss and firmness of pasta formulations followed by conventional and microwave heating as they relate to storage conditions are presented in Figures 29, 30, and 31. Three month storage decreased cooked weight for all pasta formulations heated by both conventional and microwave cooking. This may be due to the influence of storage conditions to promote increased crystallinity of starch and subsequently decreased hydration capacity. The hydration capacity of protein is also decreased during storage (Matz, 1962). However, cooked

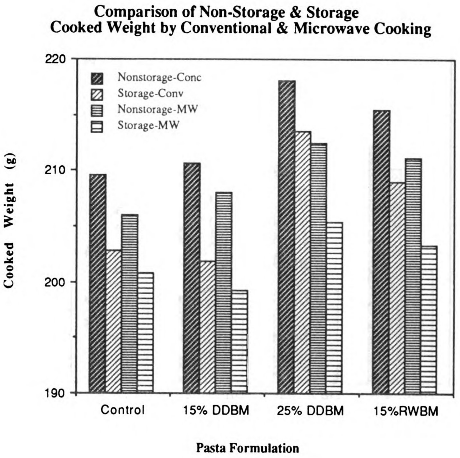


Figure 29. Comparison of mean values of non-stored and stored over all storage conditions formulated pasta cooked weight by conventional and microwave energy

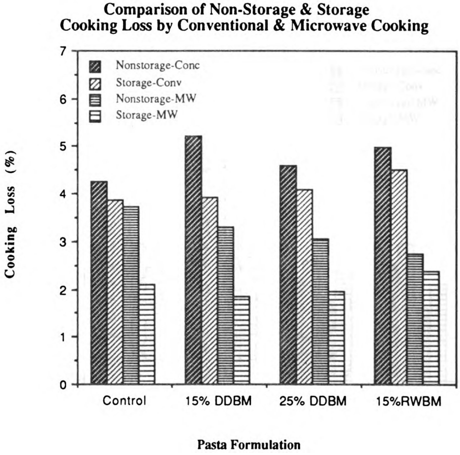


Figure 30. Comparison of mean values of non-stored and stored over all storage conditions formulated pasta cooking loss by conventional and microwave energy

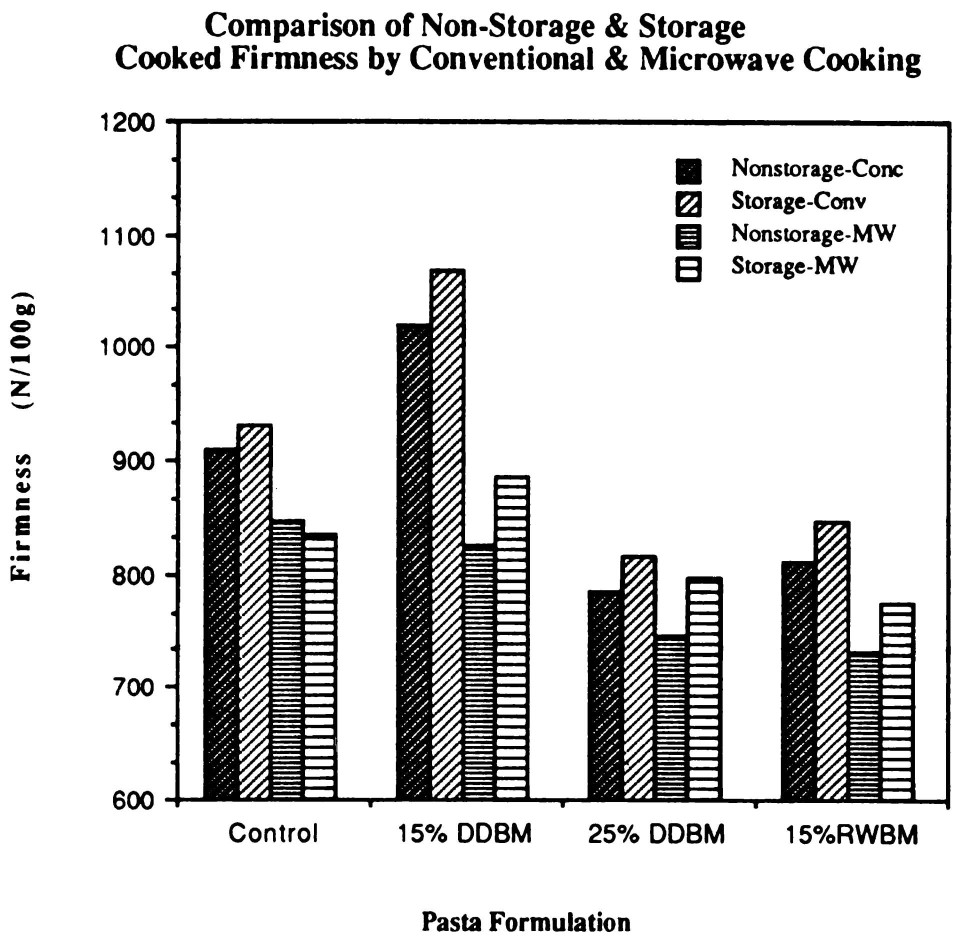


Figure 31. Comparison of mean values of non-stored and stored over all storage conditions formulated pasta cooked firmness by conventional and microwave energy

weight for storage of 25% drum-dried bean meal pasta showed a greater decreased than non-stored pasta. Storage also decreased cooking loss for all pasta formulations heated by both cooking methods, because the protein-carbohydrate interaction formed more insoluble structure. The cooking loss for all of storage pasta formulations were very similar. For both cooking methods, the cooked texture for stored pasta formulations showed firmer texture than non-stored pasta formulations except for microwave cooked control (100% Semolina) pasta. During storage, the degree of crystallinity of polymeric molecules tends to increase, with loss of the ability to solvate. Overall the food containing these structures tends to become more condensed and tougher (Matz, 1962).

SUMMARY AND CONCLUSIONS

Physicochemical characterization of precooked pasta formulated with selected bean meals showed significant differences in chemical composition and cooking quality. Pasta formulated with either drum-dried bean meal (DDBM) or raw whole bean meal (RWBM) contained higher protein, ash, fat and dietary fiber than control (100% semolina) pasta. In addition, precooked dry pasta possessed higher protein digestibility than raw ingredients (drum-dried bean meal and raw whole bean meal).

Different cooking methods significantly affected the cooked weight, cooking loss and firmness of cooked pasta. Conventional cooking (100°C/2 mins) had higher cooked weight, higher cooking loss and higher firmness properties than microwave cooking (740 Watts/5 mins). However, conventional cooking also resulted in lower nutrient retention than microwave cooking. The color of cooked pasta prepared by conventional and microwave cooking were lighter and less yellow than dry pasta.

Quantitative Descriptive Analysis showed pasta formulated with 25% DDBM had a strong bean flavor for both cooking methodologies. Pasta formulated with 15% DDBM prepared by conventional cooking had significantly higher firmness scores than control pasta. Sensory texture scores were highly associated with the instrumental maximum force data (N/100g). In addition, panelists showed pasta formulations cooked by microwave energy had greater differences than those heated by conventional energy.

Pasta formulated with bean meal did not influence the sorption isotherm curve patterns. However, higher storage temperatures resulted in significantly lower equilibrium moisture content. Following a three month storage study of pasta held at 13°C, 21°C, and 40°C, cooked weight of pasta heated by conventional method increased with increasing storage temperature, while stored pasta heated by microwave energy resulted in decreased cooked weight. Both conventional and microwave energy heated stored pasta decreased cooking losses as storage temperature increased. In addition, Storage condition greatly affected cooked pasta firmness prepared by microwave cooking. High storage temperature and high relative humidity resulted in increased cooked pasta firmness.

The color change of control (100% semolina) pasta was significantly affected by high storage temperature and high relative humidity condition stored for three months. Stored pasta formulated with 15% DDBM had significantly higher firmness at all relative humidities for conventional cooking. Regression analysis of cooked weights and cooked firmness demonstrated a highly significant relationship between these measures for both cooking methodologies.

Over all, extrusion cooked pasta was suitable for microwave cooking. In addition, pasta formulated with 15% drum-dried bean meal showed good cooking quality and was similar to control pasta heated by microwave energy compared to that which was heated by conventional energy. Therefore, pasta formulated with drum-dried bean meals showed high technological potential for the consumer markets and possesses the potential to increase the utilization of beans in western diets.

RECOMMENDATION FOR FURTHER RESEARCH

The following study areas should be considered:

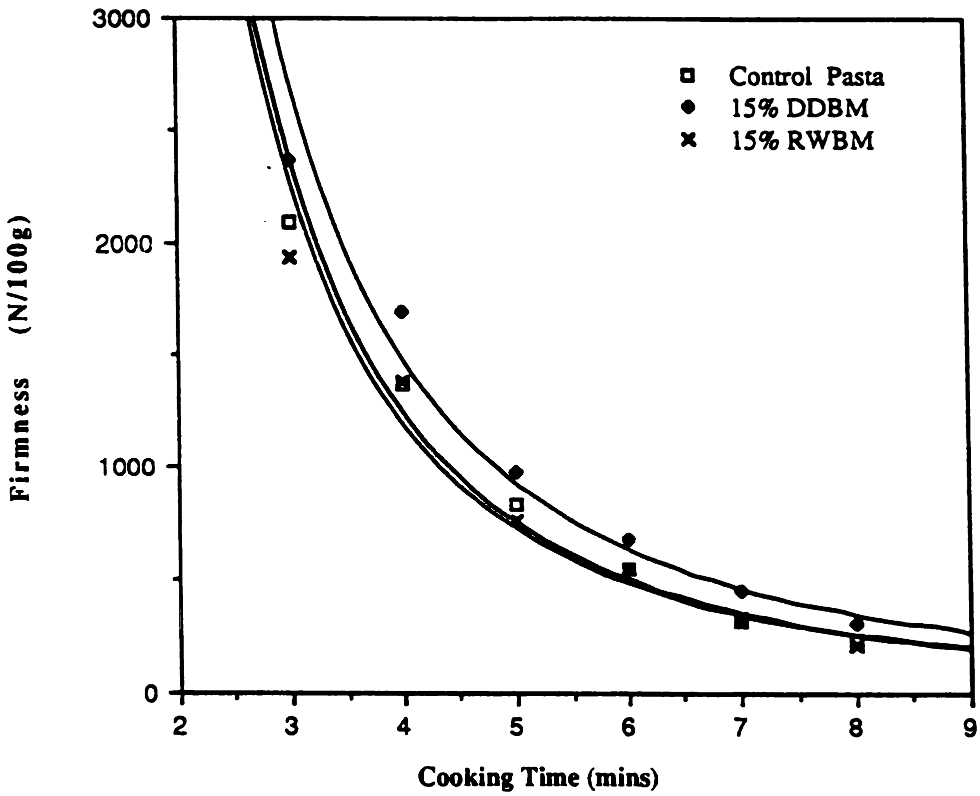
1. Study of the differences of microwave power and the heating uniformity of microwave energy and its effect on the textural quality of precooked pasta products.

2. Assess the optimum operational conditions for high-temperature short-time extrusion and drying temperatures to produce precooked pasta with superior microwave cooking quality.

3. Evaluate changes in ingredient formulations for pasta to include use of emulsifying agents and selective binding agents which improve cookability and mouth feel.

4. Evaluate packaging and reheating containers which increase convenience and improve heat distributions within the pasta during microwave heating.

APPENDIX I



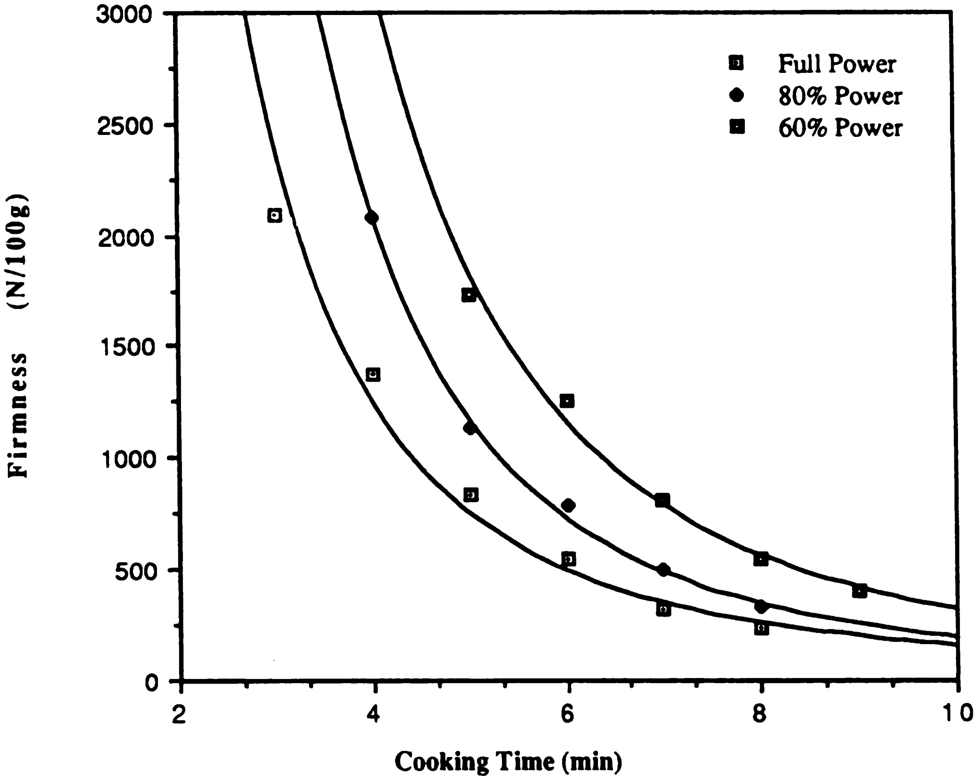
Control Pasta y = 2.8937e+4 * x^-2.2663 R^2 = 0.983

15% DDBM y = 2.7566e+4 * x^-2.1069 R^2 = 0.981

15% RWBM y = 2.7249e+4 * x^-2.2554 R^2 = 0.974

Figure 32. Cooking firmness curves for pasta formulated with selected bean meals and heated by microwave oven for different cooking time (4, 5, 6, 7, and 8 minutes)

APPENDIX II



Full Power (740 Watts) y = 2.8937e+4 * x^-2.2663 R^2 = 0.983

80% Power (592 Watts) y = 7.7133e+4 * x^-2.6000 R^2 = 0.996

60% Power (444 Watts) y = 1.0597e+5 * x^-2.5176 R^2 = 0.992

Figure 33. Cooking firmness curves for control (100% semolina) pasta heated by microwave oven using different power (Full power - 740 Watts; 80% Power - 592 Watts; 60% Power - 444 Watts)

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