PHYSICOCHEMICAL PROPERTIES OF COMMERCIAL GUMS AND THEIR EFFECTS ON PROCESSING AND COOKING QUALITY OF NONTRADITIONAL PASTA

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Physicochemical Properties of Commercial Gums and Their Effects on Processing and Cooking Quality of Nontraditional Pasta

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

Processing characteristics and quality of pasta made from durum flour and semolina and the physicochemical properties of commercial gums and their effects on processing and cooking quality of nontraditional pasta were investigated. An initial experiment was conducted using semolina and durum flour fortified with nontraditional ingredients (soy flour or oat flour, 10% w/w) and xanthan, guar or locust bean gums (2% w/w). A second set of experiments were conducted to determine the effect of commercial source of food gums on their effect on the processing and cooking quality of nontraditional pasta.

Proper hydration of nontraditional ingredient blends was more easily achieved with durum flour than semolina. Nontraditional ingredients tended to over-hydrate semolina resulting in large aggregates that adhered to metal surfaces, all of which made mixing and pasta processing difficult. Initially, dough strength was greater with durum flour than with semolina, but semolina had better dough stability over time. Soy and oat flours reduced dough strength. Xanthan and guar gums increased dough stability, particularly with durum flour. Pasta made with durum flour generally had greater cooking loss and lower cooked firmness than pasta made from semolina. Soy and oat flours reduced cooked firmness and increased cooking loss. Guar and locust bean gums did not affect cooking quality of pasta. Xanthan gum increased cooked firmness of pasta.

Samples of each gum were obtained from three different commercial vendors. For each food gum, samples varied in bulk density, molecular weight, viscosity in distilled water and the magnitude of effect on dough strength with gum source. The effect of xanthan, guar and locust gums on hydration, dough strength, and cooking quality was not affected by the source. The

magnitude of the increase in dough strength caused by xanthan and guar gums varied among their respective vendors.

Results indicated that processing was easier with durum flour but pasta quality was better with semolina. Sources of gum did not influence the effect of gums on pasta processing or quality. Even though dough strength was affected, then in the end, no effect on the final pasta quality was observed.

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DEDICATION

With immense feelings of respect and love, I would like to dedicate my dissertation to my late maternal and paternal grandfather's, Sardar. Jaswant Singh Pannu and Sardar. Jaghminder Singh Sandhu, whom I miss every day and will never forget till last day of my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

FORMAT OF DISSERTATION

This dissertation has an overall Abstract, General Introduction, and Literature Review. The literature cited in the Introduction and the Literature Review are given at the end of each section. The dissertation is written as four separate papers. Each paper has an abstract, introduction, materials and methods, results and discussion, and conclusion followed by literature cited. At the end of the four papers, there is an Overall Conclusion and a brief discussion called Future Research and Applications. Due to the format of the dissertation, there is redundancy in some places.

GENERAL INTRODUCTION

Pasta is consumed as a staple food in most countries. Traditional pasta is made from semolina (coarsely ground endosperm of durum wheat, *Triticum turgidum* var. durum). Semolina has low contents of protein, minerals, vitamins and dietary fiber. Semolina proteins contain low amounts of lysine, methionine and threonine (Kies and Fox 1970; Heger and Frydrych 1987). Therefore, with an aim to improve the nutritional quality and to add variety to the culinary experience, various nontraditional ingredients such as soy (*Glycine max*) flour (Ugarcic et al 2003; Shorgen et al 2006), flaxseed (*Linum usitatissimum*) flour (Marconi and Carcea 2001; Sinha et al 2004), and oat (*Avena sativa*) flour (Knuckles et al 1997; Yokoyama et al 1997; Brennan and Cleary 2005) have been added to pasta.

Both semolina and durum flour are products obtained from the ground endosperm of durum wheat which differs in terms of granulation. Sixty to seventy percent of commercial semolina granules lie between 425 to 250 μm (Twombly and Manthey 2006) while commercial durum flour has fine particle size with 87% of particles smaller than 250 μm (Sandhu 2012). Granulation plays an important role during hydration/mixing stage of pasta processing. Large particles would hydrate much slower than do small particles. Subsequently, small particles would tend to overhydrate while large particles tend to under hydrate. Over-hydration would result in stickiness of semolina. Under-hydration results in poor gluten network formation. Use of durum flour and/or semolina for pasta processing is expected to affect dough quality and overall quality pasta containing nontraditional ingredients and gums.

Quality of pasta made from nontraditional ingredients has been reported to be influenced by quality of semolina and nontraditional ingredients. Pasta made with flaxseed flour had better cooking properties when made with strong than with weak gluten semolina (Sinha and Manthey

2008). Yalla and Manthey (2006) reported that nontraditional ingredients differed in the magnitude of their effect on dough strength and on the subsequent extrusion properties. Nontraditional ingredients tend to change the rheological, extrusion and cooking quality of pasta (Zhang and Moore 1997; Manthey and Schorno 2002, 2004; Sinha et al 2004). Nontraditional ingredients in a pasta dough system result in discontinuity of the gluten matrix, and in decreased dough strength, mixing stability, cooking and textural qualities of spaghetti (Manthey et al 2004).

Brennan and Tudorica (2007) studied fresh pasta quality as affected by enrichment of non starch polysaccharides (gums) and reported that the type, solubility, and the level (above 5%) of nonstarch polysaccharide addition produced products that were different from the control pasta. Generally, nonstarch polysaccharide increased the cooking losses, diluted durum protein and starch contents of pasta and affected the stickiness, adhesiveness and elasticity of pasta.

Xanthan gum strengthened the semolina dough containing flaxseed flour, increased the cooked weight and improved the cooked firmness of spaghetti (Manthey and Sandhu 2008). Xanthan gum, an extra cellular high molecular weight heteropolysaccharide, is used widely in processed foods. Xanthan gum is produced by various types of bacteria belonging to *Xanthomonas* spp. such as *X. campestris*, *X. phaseoli, X. arboricola* and *X. malvacearum* (Leela and Sharma 2000). Commercially, xanthan gum is most often produced from a gram-negative bacterium (*X. campasteris)* by an aerobic fermentation process due to its high yield and high quality that is suitable for many applications (El-Enhasy et al 2011). The production process is influenced by the type and concentration of the different carbon and nitrogen sources as well as other medium components (Umashankar et al 1996), temperature, pH, aeration and agitation (Shu and Yang 1990; Garcia-Ochoa et al 2000a, b; Letisse et al 2002; Borges et al 2008). Consequently, fermentation conditions affect the quality of xanthan gum. For example, variation

in initial concentration of ammonium chloride (NH_4Cl) during fermentation of *X. campestris* in batch cultures (synthetic media) affects the pyruvate content and molecular mass of xanthan gum (Candia and Deckwer 1999a).

Even some of the repeating units found in xanthan gum can be devoid of the trisaccharide side chain (Born et al 2002). The molecular weight values reported in the literature are very diverse. Molecular weight of xanthan gum has been reported to vary from 2×10^6 to 20×10^6 (Palaniraj and Jayaraman 2011). Variation in xanthan gum pyruvate acid content, trisaccharide side chain, molecular weight and its tendency to aggregate in solution and its stiffness reflects inherent problems associated with xanthan gum (Song et al 2006).

Xanthan gum quality may vary due to difference in the strain of microorganism used for xanthan production (Leela and Sharma 2000; Mohan and Babitha 2010) and due to difference in the processing conditions of processing units (Candia and Deckwer 1999b; Garcia-Ochoa et al 2000a). Variation in quality may also develop due to collection of gum from different batches of fermentation (Davidson 1978; Shu et al 1991; Herbst et al 1992; Peters et al 1993) and different drying methods that are used to obtain final dry xanthan gum product (Cunha et al 2000). Processing parameters during fermentation process are strictly controlled which attempt to limit batch-to-batch variation in xanthan gum quality and quantity.

Guar gum and locust bean gum are galactomannans that are used commonly in food applications including dough systems. There is an increasing trend in fortification of galactomannan gums in extruded cereal products (Parada et al 2010). Inclusion of galactomannan gums in pasta system is based primarily on their property to thicken and stabilize food matrix by binding water (Stephen and Churn 1995) and as fiber fortification (Brennan and Tudorica 2008; Parada et al 2010). Yu and Ngadi (2006) reported that guar gum ($\leq$0.3%), starch

content (≤7.5%) and moisture content (30-42%) used in formulation of noodle dough (wheat flour), enhanced the cohesion and mechanical strength (rheological properties) of instant fried noodles. Locust bean gum has been reported to increase the Rapid Visco-Analyzer viscosity of the noodle samples (Yalcin and Basman 2008).

Galactomannan gums are natural, water-swellable, non-toxic and non-ionic polysaccharides. They consist of a linear chain of (1,4)-linked *β*-D-mannopyranosyl backbone, substituted with (1,6)- linked α-D galactopyranosyl units. Guar gum is obtained from the ground endosperm of guar beans from an annual plant (*Cyamposis tetragonolobus*) and locust bean gum is extracted from the seedpods of a carob tree (*Ceratonia siliqua*). Guar gum and locust bean gum normally have mannose to galactose (Man/Gal) ratio of 2:1 and 4:1, respectively. Guar gum has greater water solubility and is a better stabilizer than locust bean gum due to its higher number of galactose branch points (Fox 1992).

Similar to other crops that are obtained from a plant origin such as wheat, oat and barley (*Hordeum vulgare*), quality characteristics of gums could also be affected by plant genetics and environmental factors. Variation in quality can have a great impact on the quality of the final product obtained. For example, genotype and environment are involved in determining the total β-glucan gum content of barley (Yalcin et al 2007). Similarly, environment can affect deposition/composition of galactomannans in leguminous guar plant and carob tree. Plants and subsequent plant based ingredients are affected by the environment in which they grow, e.g. *Acacia senegal* var. senegal gum (Karamalla et al 1998).

Commercial suppliers procure raw gum different parts of the world. This brings variation among sources of gum (Pollard et al 2008). Physicochemical properties of guar and locust bean gums and their effectiveness to perform in a food system can be impacted by source. It is

believed that this variation in quality and functionality of gums could affect final quality of the product in which they are used.

A question has arisen concerning the possible differences in effectiveness of xanthan, guar and locust bean gums obtained from different commercial sources. While there is an abundance of literature examining the quality and functionality of xanthan, guar and locust bean gums from a single commercial source in food systems, published research comparing the effectiveness of xanthan, guar and locust bean gum from different commercial sources is quite limited. Also no literature has been found where they have studied the effect of commercial source of gums on processing properties and cooking quality of pasta containing nontraditional ingredients. Therefore, this study was undertaken with an aim to compare and characterize xanthan gum, guar gum and locust bean gum as obtained from different commercial sources and to see their affect on the processing quality of pasta that contained the nontraditional ingredients of soy flour and oat flour.

This study will help us understand whether gums perform better in semolina or durum flour system. Performance of gums related to hydration, dough strength, extrusion and cooking quality of nontraditional pasta will be determined and compared both in semolina and durum flour system.

Hence this research was conducted to determine:

1. the efficacy of using durum flour compared to semolina when making pasta that contains gums and nontraditional ingredients.
2. the effect of guar gum, locust bean gum, and xanthan gum on dough, extrusion, and cooking quality of pasta containing nontraditional ingredients.

3. the effect of commercial sources on physicochemical characteristics of guar gum, locust bean gum, and xanthan gum and their effects on processing and cooking quality of nontraditional pasta.

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LITERATURE REVIEW

Durum Wheat Grain

A durum wheat kernel is a dry, one-seeded fruit. Durum is a tetraploid wheat with genomes AABB [2n, = 4x = 28] (Liu et al 1996). Durum wheat grain comprises of major components starchy endosperm, aleurone layer, bran layer and germ. Durum wheat endosperm has the hardest texture of all wheats (Liu et al 1996). The size, shape and composition of starch and protein granules in endosperm cells vary depending upon their location in the kernel (Ziegler, 1969). Compared to bread wheat, durum wheat endosperm contains about twice the concentration of xanthophylls or lutein (not carotene) pigments (Sims and Lepage 1968; Boyacioglu and D'Appolonia 1994). The pericarp and seed coat layers that form the bran are separated during the milling process. The aleurone, adjacent layer to bran is part of the endosperm usually remains attached to the bran during the conventional milling. Vitamins and minerals are mostly concentrated in the aleurone layer. Wheat germ, a structurally separate entity of kernel contains the embryo and the scutellum. It constitutes about 2-3% of the kernel by weight and is rich in oil and protein (Hoseney 1998).

The physicochemical quality of durum wheat is major factor for determining the suitability of crop for its end use quality and certainly is responsible for the quality of pasta (Mariani et al 1995). Factors such as genotype (Troccoli et al 2000), environment (Kovacs et al 1997; Sharma et al 2002) and interaction between genotype and environment have been known to affect quality of durum wheat. The relationship between the physical (such as density, test weight, kernel size and kernel weight) and chemical characteristics (such as moisture, starch and protein content) have been extensively studied in *Triticum aestivum* (Igrejas et al 2002a, b; Khatkar et al 2002; Chung et al 2003; Kim et al 2003) and durum wheat (El-Khayat et al 2006;

Sissons 2008). The key features of durum wheat include its hardness, intense yellow color and nutty taste (Sissons 2008). Durum wheat kernels are larger, more vitreous and much harder than that of common hard wheat. The degree of vitreousness of kernel has been linked to the hardness of the kernels and the amount of starch and protein within the kernel (Stenvert and Kingswood 1977). Vitreousness has an important impact on the milling of durum wheat because it affects semolina yield, granulation and protein content (Matsuo and Dexter 1980). Kernel hardness is another important factor that determines end use quality of durum wheat. It presents a technical challenge in the process of grinding durum wheat kernel to semolina and/or durum flour because it has significant impact on the fracture characteristics of kernel (Symes 1961). It subsequently affects factors such as the conditioning of wheat before milling, particle size of flour, quantity of damaged starch, water absorption, and milling extraction rate (Hoseney 1987, Pomeranz and Williams 1990; Delwichie 1993; Samaan et al 2006) and rheological properties of dough formed (Samaan et al 2006).

Durum wheat endosperm is milled to flour or to a granular product called semolina which is used for making pasta products. Regulations by the U.S. Food and Drug Administration-FDA (2011) defines semolina as food prepared by grinding and bolting cleaned durum wheat to such fineness that it passes through a No. 20 sieve, but not more than 3% passes through a No. 100 sieve. It is free from the bran coat, or bran coat and germ, to such an extent that percentage of ash therein calculate on moisture free basis is not more than 0.92% and moisture content not more than 15%. When reduced to flour, the percentage starch damage is higher than when reduced to semolina.

Semolina and/or flour color is an important parameter that contributes to pasta quality. Durum wheat has high level of yellow carotenoid pigment known as lutein, which gives

characteristic yellow color to milled semolina/flour. Semolina looks more yellow than flour mainly because semolina has a coarser particle size than flour. Durum wheat quality plays a major role in milling performance. Protein levels of durum wheat for milling to semolina should be between 13-16%. Other characteristics that are important for durum wheat quality from milling perspective are test weight, 1,000 kernel weight, sprout damage, gluten strength, kernel color, vitreousness or discoloration (Feillet 1984; Peyron et al 2003).

Durum wheat is used extensively for human food consumption, most often in the form of semolina that is used in traditional pasta making; however, durum flour is also used for making pasta products. Many different kinds of food products are available, such as pasta (spaghetti, lasagna, elbow macaroni) used worldwide, and some other regional foods, such as couscous, burghul, frekeh, puffed cereals, hot cereals, desserts, single- and two-layered flat bread, leavened bread, and noodles (Dick and Matsuo 1988).

Durum wheat protein (gluten) content, kernel hardness and vitreousness have been known to affect optimum cooking time and firmness of pasta (Samaan et al 2006). The selection of semolina for pasta making is dependent on factors that affect dough development and the quality characteristics of finished products such as ash content, semolina color and cooking performance (Troccoli et al 2000). The semolina/flour particle size distribution, the protein content and quality, and the starch properties (level of damaged starch and swelling power) are important pasta quality determining parameters (Dexter et al 1983; D'Egidio et al 1990; Grant et al 1993; Delcour et al 2000a, b; Oak et al 2006; Cubadda et al 2007). Semolina particle granulation and distribution affects dough development. Preferably, semolina particles should be fine and as uniform as possible. High ash content in semolina can impart brown hue to pasta products (Borrelli et al 1999). Premium grade semolina generally has ash content lower than

0.9% (Cubadda 1988). The pigment degradation during the pasta processing has shown to be indirectly affected by the semolina ash content (Borrelli et al 1999). Semolina with bright yellow color, is most preferred for pasta production.

Protein

Wheat flour/semolina proteins are classified as albumins (soluble in water), globulins (soluble in dilute salt solutions; insoluble at high salt concentrations), gliadins (soluble in 70% ethanol) and glutenins (soluble in dilute acetic acids and bases) (Osborne 1907). Albumin and globulin proteins are mainly present in outer layers of wheat grain and provide structural integrity whereas, glutenins and gliadins (also known as storage proteins) are mainly found in the endosperm of wheat flour (Hoseney et al 1969; Bietz and Wall 1975; Tatham and Shewry 1995). Albumins and globulins have a molecular weight of up to 20,000, whereas the molecular weight of gliadins range from 30,000 to 125,000 and that of glutenins range from 100,000 to several million (Jones et al 1961).

Proteins are polymers of amino acids arranged in a linear chain joined together by peptide bonds. Twenty different amino acids occur naturally in most proteins and each amino acid has an amino group, carboxylic group, and a side group referred to as 'R'-group. Characteristics of R-group influence how protein interacts with other proteins and other components in the dough system. Sulfur containing amino acids, through the formation of disulfide bonds, are mainly involved in linking peptides together.

Glutamine is the major amino acid present in storage proteins (about 40%) (Woychik et al 1961). Proline is another amino acid that is present at high levels in gliadin (about 15%) and glutenin (about 10-12%). Cysteine has a sulfur containing R-group and constitutes 1-3% of gluten proteins (gliadins and glutenins). In comparison, albumins and globulins are high in

amino acids (g/100 g of protein) such as lysine (4.8 and 5.1), arginine (2.2 and 3.1), cysteine (2.8 and 2.2) and aspartic acid (7.7 and 8.0), but are low in glutamine (5.2 and 10.7) and proline (9.4 and 4.8, respectively) (Hoseney1998).

In relation to pasta quality, protein content of durum wheat kernels is an important quality characteristic (Dexter and Matsuo 1978, Dexter et al 1980; Autran and Galterio 1989). Protein content is influenced more by the environment than by genotype (Mariani et al 1995). High temperature regimen (37/ 28°C day/night regimen) shortens the duration of the grain fill (Altenbach et al 2003), reduces starch and protein contents per grain (DuPont et al 2006a; Hurkman et al 2003), decreases the levels of enzymes involved in starch biosynthesis (Hurkman et al 2003) and alters the relative amounts of specific gliadins, high molecular weight glutenin subunits (HMW-GS), and low molecular weight glutenin subunits (LMW-GS) (DuPont et al 2006b).

Gluten proteins have unique rheological ability to develop dough matrix that determines pasta firmness and cooking quality (Hoseney 1998). Gliadin represents heterogenous mixture of proteins that contains α-, γ-, ω- gliadins. Cysteine residues present in α-, γ- type gliadins are involved in intrachain disulfide bonds while ω- gliadins lack cysteine residues. Glutenin consist of glutenin subunits that are high molecular weight and low molecular weight. Low molecular weight glutenin subunits are classified as B-, C- and D-type, which are capable of forming both intra and interchain disulfide bonds among themselves and with high molecular weight glutenin subunits resulting in development of glutenin polymers (Veraverbeke and Delcour 2002).

Gluten proteins when hydrated, yields the gluten complex that have viscoelastic properties. Gliadin imparts the viscous while glutenin imparts elastic properties to the gluten complex. When mixed in a dough and water and other components of semolina and/or flour,

gluten forms a three dimensional continuous network (Atwell 2001). Viscoelasticity of gluten proteins is an important characteristic that influences dough development and its quality for pasta production.

Starch

Starches are complex carbohydrates (polysaccharides) that are made of glucose molecules, which plants use to store energy. Starch occurs as discrete particles, known as granules and is found in plant tubers, leaves, and seed endosperm (Buleon et al 1998). Starch granules differ in size and structure depending on botanical origin (Seib 1994; Zobel and Stephen 1996; Buleon et al 1998; Fredriksson et al 1998).

Starch granules are made up of two types of α-glucan: amylose and amylopectin. Amylose is a linear chain of (1→4) linked α-D-glucopyranosyl units with very few α-D (1→6) branches and amylopectin is a branched molecule joined together by (1→4) linked α-D-glucopyranosyl units with (1→6) glycosidic branches. Molecular weight of amylose is 1×10^5 to 1×10^6 (Mua and Jackson 1997; Biliaderis 1998; Buleon et al 1998), and a degree of polymerization (DP) by number (DPn) of 324–4920. Amylose has 3–11 chains per molecule (Mua and Jackson 1997; Yoshimoto et al 2000; Yashushi et al 2002) and each chain contains approximately 200–700 glucose residues (Morrison and Karkalas 1990).

Wheat starch molecule mostly consists of 75% amylopectin and about 25% amylose (BeMiller 2009); however, waxy wheat starches almost entirely consist of amylopectin (BeMiller 2009). Molecular weight of amylopectin is in the range of 1×10^7–1×10^9 (Morrison and Karkalas 1990; Mua and Jackson 1997; Biliaderis 1998; Buleon et al 1998) and DPn within the range 9600 to15,900 (Takeda et al 2003). Amylopectin chains are shorter than amylose molecules (Hizukuri, 1986; Morrison and Karkalas 1990; Wang and White 1994; Mua and Jackson 1997;

Takeda et al 2003). Amylopectin molecule consists of A-chains, B-chains, and C-chains (Fig. 1A and B). C-chain has a reducing end with many branches known as B-chains that are further attached to A-chains (Hizukuri 1986).

The basic starch granule and its structure could be determined by the frequency and arrangement of α-1,4- and α-1,6-glycosidic linkages. Linear chains of α-1,4- bonded glucosyl residues can form helical regions when the degree of polymerization of chain residues reaches to about 10-residues. The linear regions of external chains of amylopectin form double helical arrays when aligned in the starch granule. These double helical regions are semi-crystalline and form part of the alternating crystalline and amorphous arrangement of starch (Waigh et al 2000a, b).

A term associated with starch called gelatinization is defined as loss of granular birefringence (loss of molecular organization) within starch. It involves continuous heating of starch granules in excess water. Starch takes up water and swells substantially. The slurry reaches its highest level of viscosity, where additional mixing and heating distorts starch and releases soluble starch in water, and ultimately, the starch granules breaks apart. Remnants of starch granule continue to take up water and soluble starch both increases the viscosity of solution.

Changes that occur in starch granule after gelatinization are termed as pasting. At this stage when shear force is applied to the starch paste, molecules of starch granule orient themselves in the direction that system is being stirred and causes shear thinning of starch paste. Cooling at this stage would rapidly increase viscosity of starch paste called setback, a phenomenon where energy of the system lowers and enhances hydrogen bonding between starch chains and results in increased viscosity. Changes that occur in starch granule after gelatinization

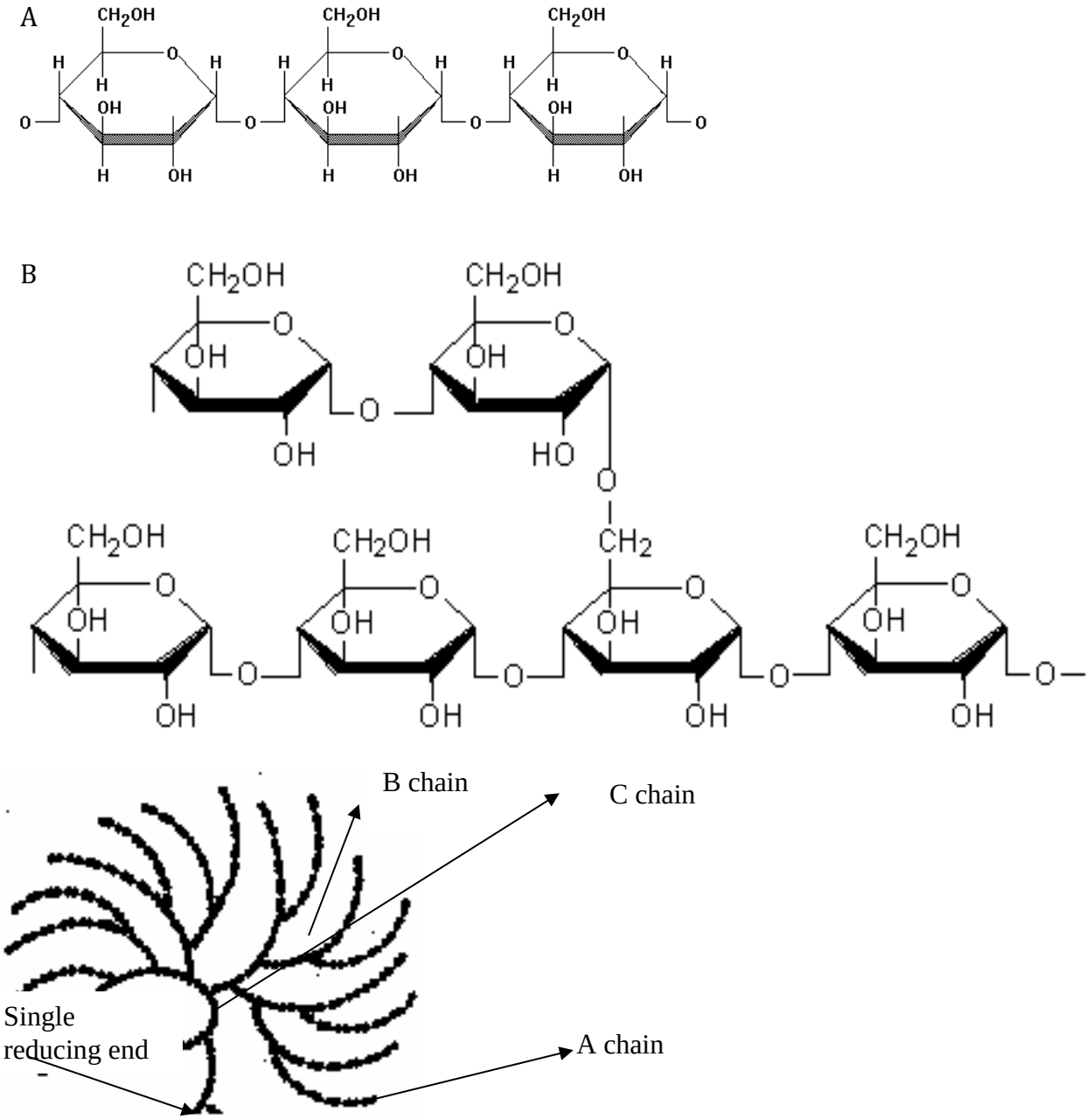

Fig. 1. Schematic representation of a section of amylose (1) and amylopectin (2) indicating the branching pattern of unit (1→4)-α-chains (A, B_1–B_3) joined together by (1→6)-α- linkages (branch points). (A) Schematic representation of amylose, Adapted from http://www.mansfield.ohio-state.edu/~sabedon/biol1025.htm. (B) Schematic representation of amylopectin chains, Adapted from http://www.rsc.org/Education/Teachers/Resources/cfb/carbohydrates.htm. (2) Adapted from http://biochemistryquestions.wordpress.com/2008/09/26/polysaccharides/ acylphosphatidyl-ethanol-amine [APE]) (Morrison 1988; Carr et al 1992).

gelatinization are termed as pasting. At this stage when shear force is applied to the starch paste, molecules of starch granule orient themselves in the direction that system is being stirred and causes shear thinning of starch paste. Cooling at this stage would rapidly increase viscosity of starch paste called setback, a phenomenon where energy of the system lowers and enhances hydrogen bonding between starch chains and results in increased viscosity. When a starch paste is allowed to cool it forms a gel, which is a liquid system that has the properties of a solid. Long storage of a gel gives rise to increased interaction between starch chains and eventually forms crystals. This process is called retrogradation and as retrogradation progresses, the gel becomes more opaque, rigid and rubbery (Hoseney 1998).

Gelatinization and retrogradation are important starch properties that affect pasta quality. In hydrated semolina, mixing causes gluten to form a continuous matrix and starch granules act as filler within the matrix. Protein-starch bonding has significant importance in durum dough linear viscoelastic behavior (Edwards et al 2002). In semolina, gluten is glassy but upon hydration it becomes rubbery and elastic with an ability to form strands and sheets during extrusion. Drying of pasta at high temperatures denatures gluten proteins to provide cross-linking desired to entrap starch granules. Protein matrix helps trap starch granules and retain its shape during the cooking of pasta.

Lipids

Lipids are important components despite being 1 to 3% (db) of the grain. Lipids in semolina exist as starch bound and non-starch bound lipids. Starch bound lipids form a complex with amylose helix (Morrison 1978) whereas non-starch lipids refer to free (soluble in non-polar solvents) and bound lipids (soluble in cold polar solvents) in the grain. In durum semolina, free lipids represent 64% of total lipids and have known to affects pasta making quality (Laignelet

1976; MacRitchie 1984). Other lipids that are present in durum wheat include, hydrocarbons (0.0036% db), sterols (25-38 mg/100g of wheat), glycerides (mainly triacylglycerides), fatty acids, glycolipids and phospholipids (Youngs 1988). Lipids contribute to color of semolina/pasta primarily due to the xanthophyll (lutein) pigments (Sissions 2008). Lipids form complex with starch (amylose polymers) and resists leaching out of starch granule during pasta cooking thus improving the quality of cooked pasta.

Non-starch Polysaccharides

The non-starch polysaccharides found in bread wheat (with similar values in durum wheat) account for 3 to 8% of the grain and consists of cellulose (3 to 7% db), β-glucans (1%), arabinogalactan-peptides and arabinoxylans (7.6%) (Stone 1996). Compared to starch and protein, arabinoxylan is a minor component of grain but has a major effect on the use of cereal grain due to its hydration properties and ability to form viscous solutions (Sissons 2008). Arabinoxylan is the main polymer in wheat cell walls and has been classified into water extractable and water unextractable forms (Courtin and Delcour 2002). Brijs et al (2004) added two different endoxylanases (an enzyme that hydrolyzes xylan back bone in random manner) with different substrate specificities in the pasta dough. One enzyme hydrolyzed water unextractable and other hydrolyzed water extractable anabinoxylans and showed minimal impact on pasta color, cooking time and firmness.

Pasta

Pasta is consumed as a staple food in most countries. Traditional pasta is made from semolina. Cooked pasta of al dente quality is considered the ideal quality. It is firm and resilient with no surface stickiness and little cooking losses (Dexter et al 1985; Troccoli et al 2000; Wood et al 2001; Sissons et al 2005). Durum wheat makes the best quality pasta due to its characteristic

gluten quality and color (Kill 2001). Different parameters influence pasta processing and the final product quality.

Durum semolina is hydrated with water to approximately 31% moisture content for long goods and to 32-34% for short goods. Hydrated semolina is then kneaded into dough through the interaction among hydrated semolina, extrusion barrel, and the extrusion auger into a homogeneous mass before extrusion through a die. Low moisture in long goods minimizes stretching during extrusion. High moisture in shorter goods enables mechanical action of the cutter blade not to tear the extruded product. Pasta obtained from the extruder is then dried to moisture content of approximately 12%.

Role of Semolina and/or Flour Components in Pasta Making

Semolina Proteins

Gluten quantity and composition are predominant factors that are linked with superior pasta texture. Before drying pasta at elevated temperatures, the glutenin component had already formed networks in extruded dough. Networks are transient as they arise from entaglement of glutenin subunit polymers and dynamic thiol-disulfide exchange reactions (Veraverbeke and Delcour 2000). Gliadin determines viscous properties of the gluten network. High temperature and low moisture drying of pasta ensures high firmness and low stickiness in cooked pasta (Dexter et al 1981, 1983; Zweifel et al 2003; Baiano and Del Nobile 2006). Elevated temperatures involved in pasta drying causes protein disulfide cross-linking by oxidation of glutenin free sulfhydryl groups (Largain et al 2005, 2008) and forms large protein polymers (Lammacchia et al 2007). Protein polymerization, as a result of drying, is monitored by measuring contents of protein extractable in dilute sodium dodecyl sulfate solution. The amount of proteins unextractable is considered as the measure of protein polymerization. The importance

of disulfide bonds in stabilizing protein polymers was demonstrated by early studies in which the addition of disulfide reducing agents was shown to weaken doughs and result in increased glutenin solubility (Shewry et al 2002).

During the cooking process, there is a physical competition between starch swelling and the properties of polymerized and polmerizing proteins (Resmini and Pagani 1983; Delcour et al 2000a, b). In good quality pasta, a strong protein network prevents negative impact of starch swelling such as breaking protein network and leaching of starch, which accounts for firmness and elasticity of pasta (Resmini and Pagani 1983).

Protein matrix holds starch granules during the cooking process, thereby reducing losses and surface stickiness during cooking. Semolina with a low protein level develops fragile spaghetti with low firmness. High protein semolina allows spaghetti to swell when cooked (affects mouthfeel), reduces cooking losses and retains firmness during overcooking (Dexter et al 1983).

The impact of glutenin subunits, their allelic composition and gliadin affect on dough properties and pasta quality has been studied extensively in past (Ammar et al 2000; Brites and Carrillo et al 2001; Sissons et al 2005). The influence of high molecular weight glutenin subunit 1 on dough properties has been shown to have a positive affect on gluten strength (Brites and Carrillo 2001; Martinez et al 2005). Edwards et al (2003) documented that low molecular weight glutenin subunit 2 strengthened the dough more than low molecular weight subunit 1. Direct mapping of disulfide bonds has demonstrated the presence of inter-chain bonds between HMW subunits and between HMW and LMW subunits, with one intra-chain bond within the N-terminal domain of an x-type subunit (Kohler 1997; Shewry and Tatham 1997; Kasarda 1999). Disulfide bonds are, therefore, widely considered to be essential for gluten visco-elasticity.

Gluten strength is a result of balance between viscosity and elasticity (Shewry et al 2002). Gluten index test (a ratio) is commonly used for determining durum wheat gluten strength (Cubbada et al 1993).

Semolina Starch

In pasta, durum wheat semolina proteins have been recognized as of the utmost importance for pasta quality. More insight into the role of starch in pasta quality has documented that the starch in pasta is no longer considered to be an inert filler. Starch is a substantial, active, and quality determining part of the pasta structure, because of its interactions with other semolina components (Preston et al 1998).

Frey (1970) studied the role of starch and proteins in pasta system and reported that starches of varying botanical origin in the model pasta had a large influence on its consistency. Wheat and maize starches yielded the best pastas. Incorporation of severely cross-linked wheat starch in the model pasta yielded a porridge after cooking, suggesting that the gelatinization properties of starch are of crucial importance for good cooking quality. D'Egidio et al (1990) assessed the relative importance of starch and amylose with a multiple variance analysis and reported that in pasta, amylose was responsible for 37% of the pasta quality. It was further suggested that a better-finished product is obtained if less starch is damaged during the pasta processing. Too fine granulation in semolina (<210 μm) leads to greater starch damage, which causes increased cooking losses in bran rich pasta (Gauthier et al 2006) and lower cooked firmness and high water absorption in wholewheat pasta (Manthey and Schorno 2002). Sensidoni et al (2003) reported that fine semolina granulation could increase the amount of reducing sugars in the dough mixture by allowing endogenous α-amylase to produce reducing sugars.

Delcour et al (2000b) reported that the surface characteristics of starch are of little importance for its interaction behavior. Gluten-starch interaction in raw pasta is mainly due to physical inclusion of starch in the gluten network. High-temperature drying promotes the coagulation of protein fractions into a continuous network (Resmini and Pagani 1983). Drying renders the starch granules less extractable and restricts their gelatinization and swelling during the cooking. Consequently, the quality and quantity of this network correlate with the physical properties of the cooked pasta (Resmini and Pagani 1983). In this context, Delcour et al (2000a), stated that all reconstituted pasta samples had generally the same cooking quality and concluded that the slight changes in starch gelatinization behavior that are caused by the starch modifications (lipid removal/ deproteination/changed granule size distribution) are of little importance for pasta quality.

Soh et al (2006) reported that increased amylose contents (above normal levels ~ 24 to 28%, as found in durum wheat) had greater tendency to develop firmer pasta. Granules are more tightly packed in high amylose starches, which on swelling offer more resistance to rupture and deformation thus increasing firmness in pastas. Elevated amylose contents were also associated with decreased water uptake and increased cooking losses in pasta. Soh et al (2006) also reported that spaghetti made from samples that had higher percent of B-starch granules (32 to 40%), had higher cooked firmness and low stickiness compared to control (with 22.7% B-granules). Elevated B-granule content has been known to decrease cooking loss in pasta (Vasanthan and Bhatty 1996). Lower cooking loss has been linked to smaller size of B-granules, which has greater surface area, and its increased percentage might extends interactions between starch granules and gluten, which would account for decreased loss of amylose and reduced cooking loss in pasta (Vasanthan and Bhatty 1996).

Semolina Lipids

It is well known that lipids play an important role in determining color of pasta (Sissons 2008). Lipid content does not decrease during pasta processing but undergoes chemical changes or complexes with proteins and starches under the application of mechanical stress during the extrusion (Laignelet 1976). When added to dough, monoacylglycerides with saturated fatty acids complex with amylose, which results in decreased pasta stickiness and improved tolerance to overcooking (Laignelet 1976; Matsuo et al 1986). The dough mixing process accelerates interaction between free lipids and flour components especially proteins and beneficially influences gluten strength. Mixing process also enhances hydrophobic bonding between non-polar lipids and acid soluble components such as glutenin, gliadin, albumins and nitrogenous nonproteins, polar lipids interact with glutenins, free polar lipids binds to gliadin by hydrophilic linkages. These bonds provide better structural support to gluten network (Chung et al 1978; Chung 1986).

Nontraditional Pasta

Pasta consumption patterns and marketing trends have changed largely as consumers have become diet conscious and are influenced towards nutritional diets. Semolina proteins contain low amounts of lysine, methionine and threonine (Kies and Fox 1970; Heger and Frydrych 1987), therefore, in order to add variety to existing culinary experiences and to enhance healthful and nutritional qualities of pasta, various nontraditional ingredients such as soy (*Glycine max*) flour (Ugarcic et al 2003; Shorgen et al 2006), flaxseed (*Linum usitatissimum*) flour (Marconi and Carcea 2001; Sinha et al 2004), oat (*Avena sativa*) flour (Knuckles et al. 1997; Yokoyama et al 1997; Brennan and Cleary 2005), corn (*Zea mays*) flour (Taha et al 1992),

buckwheat (*Fagopyrum esculentum*) bran flour (Manthey et al 2004), pea (*Pisum sativum*) fiber (Edwards et al. 1995) and wheat bran (Zhang and Moore 1997) have been fortified into pasta.

Studies show that nontraditional ingredients tend to change the rheological, extrusion and cooking quality of pasta (Zhang and Moore 1997; Manthey and Schorno 2002; Manthey et al 2004; Sinha et al. 2004). Nontraditional ingredients in a pasta dough system result in discontinuity of the gluten matrix, and can reduce dough strength, mixing stability, cooking and textural quality of spaghetti (Manthey et al 2004).

Quality of pasta made from nontraditional ingredients has been reported to be influenced by semolina quality. Yalla and Manthey (2006) reported that non-traditional ingredients differed in the magnitude of their effect on dough strength and on extrusion properties. Dough strength, specific mechanical energy, mechanical energy and extrusion rate were reduced more by flaxseed flour than by buckwheat bran flour or wheat bran. In addition, pasta made with flaxseed flour was better with strong than weak semolina (Sinha and Manthey 2008).

Soy in Pasta

Soy protein is rich in the essential amino acids arginine, leucine, lysine, phenylalanine, and valine (Twombly and Manthey 2006). Soy flour also contains nutraceutical compounds such as isoflavones. Studies have reported that the supplementation of soy flour in pasta imparts high protein content (~35%) and lysine, an essential amino acid (Paulsen 1961; Clausi 1971; Siegel et al 1975; Laignelet et al 1976; Haber et al 1978; Buck et al 1987; Taha et al 1992; Collins and Pangloli 1997). Soy foods have been found to have beneficial effects in reducing risks of coronary heart disease and might reduce risks for some cancers (Messina 2003; Ohr 2004; Wietrzyk et al 2005).

Pastas containing >30% soy flour have been reported to have bitter and unpleasant flavors (Siegel et al 1975; Breen et al 1977; Taha et al 1992; Singh et al 2004). Shorgen et al (2006) reported that spaghetti made with 50% soy flour had slightly greater beany and bitter flavors as compared to the control without soy. There was no significant difference in textural and flavor characteristics between spaghetti made with all durum wheat and spaghetti with up to 35% soy flour.

Oat in Pasta

Oats are a valuable source of β-glucans, which accounts for its various health benefits. Recent studies have reported that soluble fiber, such as (1-3, 1-4)-β-D-glucan (referred to as β-glucan), has been shown to have effects on the glycemic, insulin, and cholesterol responses to food (Brennan and Cleary 2005).

Limited literature is available on the use of oat flour in pasta. Studies were conducted by Inglett et al (2004) on the rheological, textural and sensory properties of Asian noodles containing an oat cereal hydrocolloid. They used an oat hydrocolloidal fiber component, called Nutrim-5, for extending the use of rice flour in making Asian noodles. Nutrim-5 is one of a family of β-glucan containing hydrocolloids that are prepared by thermo-shear processing of oat flour or bran. Rheological properties of the noodle flour composites indicated that Nutrim-5 contributed binding qualities to the composites. Nutrim-5 contributed functionality to the rice flour, allowing for larger quantities to be used in the making of Asian noodles. Use of Nutrim-5 (10% by wt) in the formulation, satisfactorily made noodles using 50% rice flour. The cooking loss and tensile strength were found to be satisfactory for this amount of rice flour in the noodles. A trained sensory panel also indicated that these noodles did not reveal any difference in taste.

Food Gums in Pasta

Brennan and Tudorica (2007) studied fresh pasta quality as affected by enrichment of non-starch polysaccharides (gums) and reported that the type, solubility, and the level (above 5%) of non-starch polysaccharide, appeared to create pasta products that were different from the control pasta. Generally, non-starch polysaccharide increased the cooking losses, diluted durum protein and starch content of pasta and affected the stickiness, adhesiveness and elasticity of pasta.

Gums are often fortified in multigrain pasta. Use of xanthan gum strengthened the semolina dough containing flaxseed flour. Xanthan gum increased the cooked weight of spaghetti and improved the cooked firmness of flaxseed flour pasta (Manthey and Sandhu 2008).

The thickening ability of xanthan gum solutions is directly related to viscosity. Highly viscous solutions resist flow. Xanthan gum solutions possess a pseudoplastic or shear thinning behavio2r in nature, accompanied by decreases in viscosity and increases in shear rate. The viscosity also depends upon temperature (both dissolution and measurement temperatures), the biopolymer concentration, concentration of salts and pH (Garcia-Ochoa et al 2000b). The pH range between 1 and 13 does not affect the viscosity of xanthan solutions. At pH 9 or higher, xanthan gum becomes de-acetylated (Tako and Nakamura 1984), while at pH lower than 3 it becomes depyruvylated (Bradshaw et al 1983). Upon the interaction of polysaccharides with proteins, associative interactions comes into play, such that when polymer amount is not too large, a polysaccharide become adsorbed onto more than one protein particle (Bungenberg de Jhond 1949).

Braga et al (2006) reported that soy protein isolate (SPI)–xanthan gels prepared without KCl were mainly stabilized by non-covalent (H-bonding and hydrophobic) and disulfide (S-S)

bond interactions; whereas in gels containing KCl, electrostatic interactions were also involved in maintaining the gel structure. The pH changes also affect viscosity and functionality of xanthan solutions. Solutions are highly viscous at low polymer concentrations, which enable its use as a thickener in various food applications (Garcia-Ochoa et al 2000b).

Huebner et al (1979) studied polysaccharide interactions (xanthan, carrageenans and alginate) with wheat proteins and flour dough. They reported that xanthan and carrageen gums increased the peak time and dough stability most effectively as measured by farinograph. Protein-polysaccharide interactions of purified gluten solutions containing partial polysaccharides were studied by determination of turbidity and viscosity. The reactions that varied from no apparent interaction to strong association and precipitation suggested a possible use of gums as scavengers for proteins in dilute wastewater solutions or in texturized protein foods.

Edwards et al (1995) conducted studies on the textural characteristics of wholewheat pasta and pasta containing non-starch polysaccharides. They reported that locust bean gum and especially xanthan gum improved pasta firmness characteristics. Food gum enriched pasta had increased tolerance to overcooking, which they attributed to the formation of a mechanical network surrounding the starch granules during cooking and subsequent gelatinization.

Sereno et al (2007) studied the impact of the extrusion process on xanthan gum behavior. Xanthan gum was extruded in a Twin Screw Clextral BC12 Extruder (Clextral, Firmeny-Cedex, France) and was dried in a vacuum oven (Sanyo Gallenkamp PLC) at 65°C for 72 h under a pressure of 100 Pa (final water content <8%). Temperatures of the barrel heating zones from the feed end were 85, 85 and 70°C. Drying was followed by the grinding of xanthan gum at room temperature and sieving using a sieve size of (250 μm). They reported that processing xanthan

gum followed by subsequent drying produced a biopolymer that had particulate behavior rather than molecular behavior in aqueous solution. The extrusion process resulted in melting and alignment of xanthan gum macromolecules. Upon cooling, reordering occurred in the highly concentrated environment in the extruder (~ 45% water w/w). There was incomplete intermolecular association between neighboring macromolecules as a result of lesser degrees of molecular moment. As a result, a structural network was created that was maintained by associations involving ordered regions. They also suggested that xanthan gum solutions could be prepared from this particulate material by dispersing and subsequent heating far more readily than can be achieved with non-processed xanthan gum.

Rosell et al (2007) studied the affect of hydrocolloids hydroxypropylmethylcellulose (HPMC), pectin, guar gum and xanthan gum on the thermo mechanical properties of wheat using mixolab (Chopin, Tripette et Renaud, Paris, France). They reported that HPMC induced greater benefits on wheat dough behavior during mechanical shearing and thermal treatment and resulted in significant increases in water absorption, dough development time and stability during mixing and decreased the extent of dough weakening during heating. Different synergistic (i.e HPMC/xanthan enhanced water absorption, HPMC/guar gum increased dough stability) and antagonistic effects (i.e. HPMC/pectin on dough development time, HPMC/guar gum on dough weakening) between hydrocolloids were observed. It was suggested that the molecular structure of polymers and formation of hydrogen bonds between wheat proteins and the non-ionic polymers might be responsible for changes in the dough stability (Rosell et al 2007).

Hydrocolloids have been shown to influence the gelatinization of starches. It is well known that hydrocolloid - starch suspensions result in synergistic increase in viscosity (Liu et al 2003). Christianson et al (1981) reported that guar gum, xanthan gum and

carboxymethylcellulose (CMC) resulted in a two-stage increase in viscosity of wheat starch during gelatinization. The initial increase in the viscosity was attributed to the first stage of swelling, while the subsequent increase in the final peak viscosity was due to interactions of gums, leached component and swollen starch granules.

Galactomannans: Guar and Locust Bean Gum

Galactomannans occur widely in the seed endosperm of plants in the *leguminoseae* family. Two galactomanans that are of greatest practical significance, as thickners and stabilizers in industrial applications, are guar gum from the annual plant *Cyamposis tetragonolobus* L. and locust bean gum (LBG) from the seed pods of carob tree (*Ceratonia siliqua* L.). Locust bean or carob gum (Fig. 2) is a polysaccharide with (1→4)-β-D-mannan backbone substituted with (1→6)-β-D-galactosyl residues (Makri and Doxastakis 2006). Galactose distribution in the mannose linear chain controls the rheological properties of locust bean gum. Solutions of LBG, particularly fractions with high M/G ratio, can dissolve only in hot water and are unstable. Higiro et al (2007) studied the rheology of xanthan and LBG interactions in dilute aqueous salt solutions. An oscillatory capillary rheometer was used to investigate the effects of NaCl, KCl, and $CaCl_2$ on the viscoelastic properties of xanthan and LBG blends in dilute solution. Any of the three salts significantly reduced the intrinsic viscosity and elastic component of the gum blends, with a pronounced effect from divalent ions as compared to the monovalent ions (Higiro et al 2007).

An endospermic leguminous seed of guar gum contains the reserve water soluble, non starch polysaccharide galactomannan. It is composed of β-(1→4)-linked D-mannopyranosyl backbone, partially substituted with α-(1→4)-linked D-galactopyranosyl side chains (Fig. 3) (Brennan et al 1996). Guar gums normally have a mannose to galactose ratio (M/G) of ~1.6, and

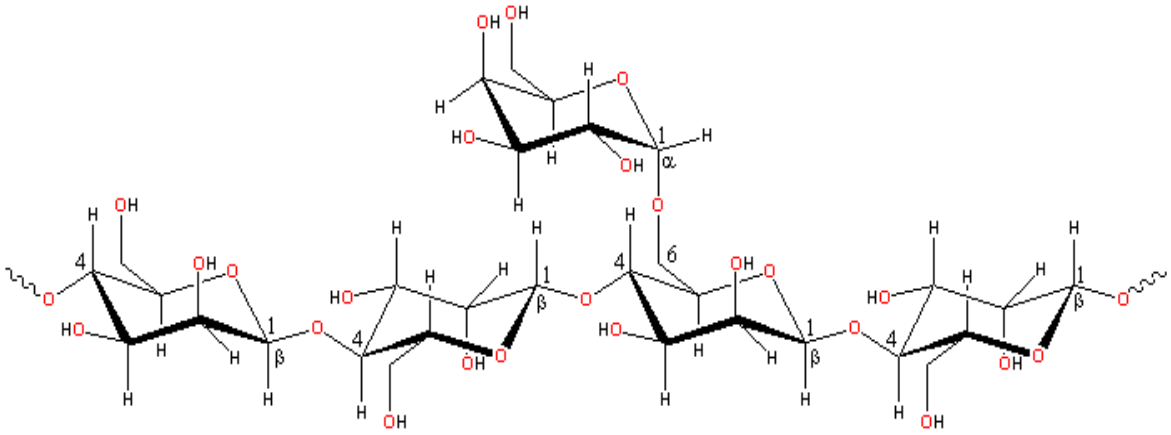

Fig. 2. Structure of locust bean gum. http://www.lsbu.ac.uk/water/hyloc.html

thus can be dissolved in cold water. It gives high viscosity in water, even when used in small quantities. Strong acids result in hydrolysis and loss of viscosity, which is also observed in solutions of strong alkali. Yadira et al (2006) studied the effect of magnesium and iron on the hydration and hydrolysis of guar gum at pH 12 as a function of viscosity. It was found that small concentrations of magnesium do not affect the dissolution ratio of guar, but significantly decrease hydrolysis at high temperatures. These results suggested that Mg $(OH)_2$ forms an adduct with the polysaccharide that prevents thermal hydrolysis of the guar.

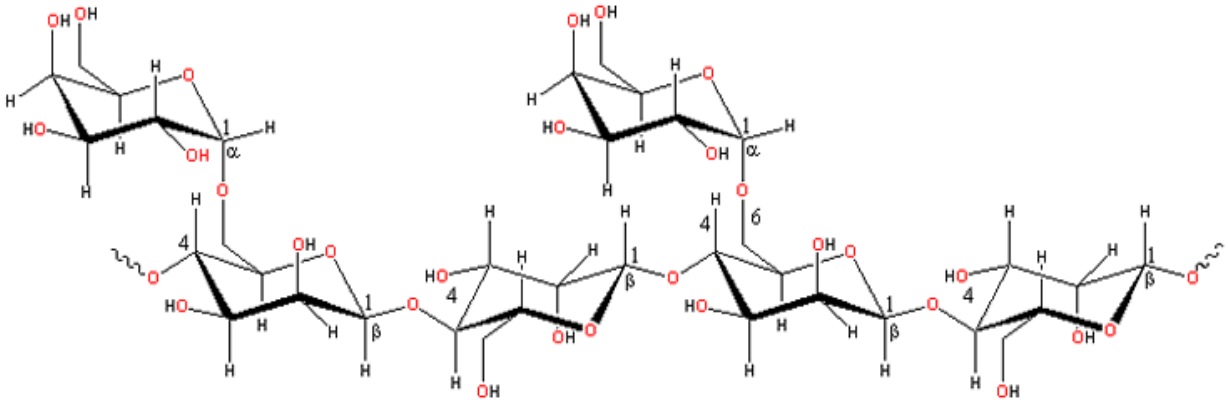

Fig. 3. Structure of guar gum. http://www.pharmainfo.net/reviews/guar-gum-better-polysaccharide-colonic-drug-delivery

Xanthan Gum

Xanthan gum is a natural microbial (*Xanthomonas campestris* pv. campestris *)* polysaccharide. Xanthan gum is an important industrial biopolymer and was discovered in late 1950's at the North Regional Research Laboratories (NRRL) of the United States Department of Agriculture (Margaritis and Zajic 1978). Xanthan gum is a heteropolysaccharide (Fig. 4) with primary structure of repeated pentasaccharide units formed by two glucose units, two mannose units and one glucuronic acid unit in the molar ratio 2.8:2.0:2.0.

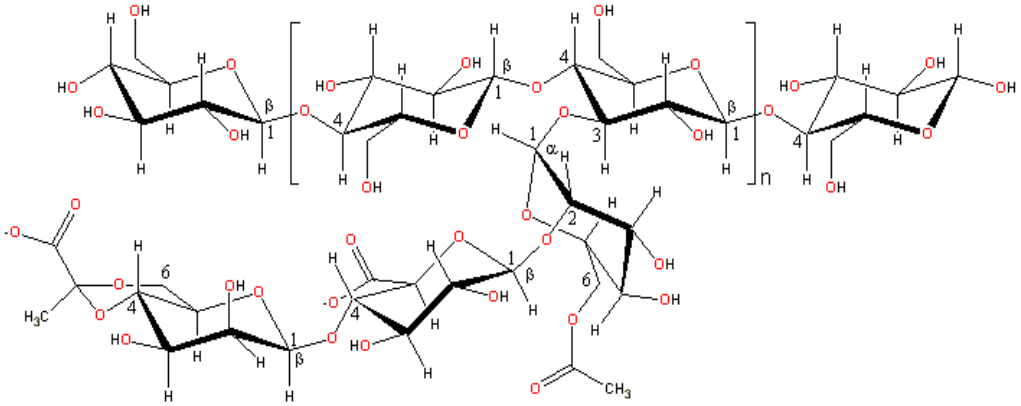

Fig. 4. Structure of xanthan gum. http://www.lsbu.ac.uk/water/hyxan.html

The main chain consists of β-D-glucose units linked at 1 and 4 positions (Garcia-Ochoa et al 2000b). Presence of acetic and pyruvic acids produces an anionic polysaccharide (Sanford and Baird 1983). The polyelectrolytic nature of the xanthan molecule allows it to be highly soluble in both cold and hot water. Solutions are highly viscous at low polymer concentrations, which enable its use as a thickener in food applications (Garcia-Ochoa et al 2000b). Xanthan has been approved for use as a food additive without any specific quantity limitations (Kennedy and Bradshaw 1984).

The efficient stabilization and suspension properties of xanthan are largely dependent upon its structural features as high molecular weight, extended conformation obtained from its

stiff cellulosic backbone and double helical conformation. The levels of acetate and pyruvate substituents affect both the structural and functional properties of xanthan (Peters et al 1993). Bacterial strain and fermentation conditions account for the extent of variation in the acetylation and pyruvylation in xanthan conformation (Cadmus et al 1976; Sandford et al 1977). Acetate substituents stabilize the double helical conformation, while the pyruvate groups destabilize the ordered form of xanthan. Low acetate xanthan gum is known to exist in more flexible, disordered conformation as compared to the standard commercial xanthan gum in low to moderate ionic strength solutions. A low acetate xanthan results in greater synergistic interactions with galactomannans and improves solubility in moderately acidic environments (Peters et al 1993).

Dissolution temperatures greatly affect gum viscosity by controlling the helical and random coil molecular conformations (Garcia-Ochoa and Casas 1994). The viscosity of xanthan solutions increased with the increase in the concentration of polymer. The presence of salts in solution also influences xanthan viscosity and functionality. The xanthan gum solution possesses a pseudoplastic or shear thinning behavior in nature, accompanied by a decrease in viscosity with an increase in shear rate. The viscosity depends upon the biopolymer concentration, concentration of salts and pH (Garcia-Ochoa et al 2000a, b). Incorporation of salts in sufficient amounts leads to precipitation or complex co-acervation (i.e phase separation of a liquid precipitate or phase when solutions of two hydrophilic colloids are mixed under suitable conditions) due to ion binding of cations of the added salts to the ionized groups on the poly anion. When all the variable anionic groups are bound to a cation, it results in charge reversal at that moment. Polyvalent cations such as calcium, aluminum and quaternary ammonium salts are effective in polymer precipitation as compared to monovalent salts such as NaCl, which does not cause any precipitation (Pace and Righelato 1981). Salts cause reduction in the molecular

dimensions of polymer due to diminished intermolecular electrostatic forces (Smith and Pace 1982).

Variation in the Functionality of Food Gums in Pasta Systems

The concept of environment and genotype affecting functionality of grain products is well established. The research presented here was conducted to determine the extent of variation in the functionality of xanthan, guar, and locust bean gum in pasta systems due to commercial source.

Xanthan gum is produced by various types of bacteria belonging to *Xanthomonas* spp. such as *X. campestris, X. phaseoli*, *X. arboricola* and *X. malvacearum* (Leela and Sharma, 2000). Commercially, xanthan gum is most often produced from a gram-negative bacterium (*X. campasteris)* by an aerobic fermentation process due to its high yield and high quality that is suitable for many applications (El-Enhasy et al 2011). The production process is highly influenced by the type and concentration of the different carbon and nitrogen sources as well as other medium components (Umashankar et al 1996), temperature, pH, aeration and agitation (Shu and Yang 1990; Garcia-Ochoa et al 2000b; Letisse et al 2002; Borges et al 2008). Consequently, fermentation conditions affect the quality of xanthan gum for example, with all other fermentation conditions kept constant, varied initial concentrations of ammonium chloride (NH_4Cl) in batch cultures of *X. campestris* in synthetic media had much obvious effect on pyruvate content than effect on molecular mass of xanthan gum (Flores and Deckwer 1999). Even some of the repeating units may be devoid of the trisaccharide side chain (Born et al 2002). The molecular weight values reported in the literature are very diverse. Variation in xanthan gum pyruvate acid content, trisaccharide side chain, molecular weight and its tendency to aggregate in

solution and its stiffness reflects inherent problems associated with xanthan gum (Song et al 2006).

Xanthan gum developed at different or same commercial location may show variation in quality due to difference in the strain of microorganism used for xanthan production (Leela and Sharma 2000; Mohan and Babita 2010) and due to difference in the processing conditions of processing units (Candia and Deckwer 1999a,b; Garcia-Ochoa et al 2000a). Variation in quality may also develop due to collection of gum from different batches of fermentation (Davidson 1978; Shu et al 1991; Herbst et al 1992; Peters et al 1993) and different drying methods that are used to obtain final dry xanthan gum product (Cunha et al 2000). Processing parameters during fermentation process are strictly controlled which limit batch-to-batch variation in xanthan gum.

It is true for galactomannans such as guar and locust bean gum. Similar to other crops that are obtained from a plant origin such as wheat, oat and barley, quality characteristics of gums could also be affected by plant genetics and environmental factors. Variation in quality can have great impact on the quality of the final product obtained. For example, genotype and environment are involved in the total β-glucan content of barley (Yalcin et al 2007). Similarly environment can affect deposition/composition of galactomannans in leguminous guar plant and carob tree. Plants and subsequent plant based ingredients are affected by the environment in which they grow (Karamalla et al 1998).

Commercial suppliers procure their guar and locust bean gum manufacturing raw material from different parts of the world. This brings variation among sources of gum (Pollard et al 2008). Depending upon the source, guar and locust bean gum could vary in its physicochemical properties and its effectiveness to perform in a food system. It is believed that

this variation in quality and functionality of gums, due to different sources, might affect processing conditions and final quality of the product in which they are used.

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PAPER 1. QUALITY OF NONTRADITIONAL PASTA WHEN MADE WITH SEMOLINA AND WITH DURUM FLOUR

Abstract

This research was conducted to compare the quality of nontraditional pasta made with semolina or durum flour. Semolina and durum flour were fortified with nontraditional ingredients (soy flour or oat flour, 10% w/w) and combined with xanthan gum, guar gum or locust bean gum (2% w/w). Hydrated ingredients were extruded as spaghetti, which was dried using a high temperature (70^{o}C) drying cycle. All values for the physical and chemical properties of gums and flour ingredients were within normal ranges found in commercial samples. Particle size of ingredients influenced the dough properties. Hydration, as measured by mixograph, was 1.8 times longer with semolina than with durum flour. Food gums had a greater impact on hydration time with semolina than durum flour. Twenty min mixogram indicated that dough strength was stronger with semolina than with durum flour. Stability of dough made with durum flour was improved by xanthan gum and guar gum but not by locust bean gum. The effect of gums on dough strength was most pronounced with xanthan gum. Both oat flour and soy flour reduced dough strength but affected dough somewhat differently. Oat flour reduced peak height by 4.5% and end height by 6.9% while soy flour reduced peak height by 8.3% and end width by 5.3% and improved dough stability of durum flour (i.e increased peak width by 2.1% and end width by 16.0 %). Effect of granulation, food gums, nontraditional ingredients and their interactions on dough properties were manifested in differences in hydration time and texture of hydrated blends, and cooking quality of spaghetti.

Introduction

Traditional pasta is made from semolina, which is the coarsely ground endosperm of durum wheat. Commercially, 60 to 70% of the semolina granules are between 425 to 250 μm (Twombly and Manthey 2006). A narrow particle size distribution is important for uniform absorption during the hydration/mixing step of pasta processing. Uneven absorption by semolina particles will result in over hydrated and under hydrated semolina particles.

During dough development, gluten matrix is formed. Gluten formation requires gliadin and glutenin storage proteins found in the endosperm, enough moisture to hydrate the storage proteins, and energy to cause the proteins to interact with each other. Gluten matrix encapsulates starch and provides for the structure and strength of the pasta (Veraverbeke and Delcour 2002). If gliadins and glutenins are not hydrated then they will not form a gluten matrix, which results in white chalky areas on and in the pasta (Manthey and Sandhu 2009). Gliadin proteins provide cohesion to the gluten matrix while glutenins provide strength and elasticity (Hoseney 1998). Over-hydration results in a sticky dough that can adhere to metal surfaces and cause problems during processing.

Semolina is low in vitamins, minerals, and fiber, while the gliadin and glutenin proteins are low in lysine and other essential amino acids. To improve its nutritional and healthful properties, pasta is fortified with minerals and vitamins and with various nontraditional ingredients (Cleary and Brennan 2006; Twombly and Manthey 2006). Nontraditional ingredients typically are ingredients that are not traditionally added to pasta but which contain compounds that are nutritionally superior to those found in semolina, including minerals, antioxidants, lignans, omega-3 fatty acids, protein rich in essential amino acids, and fiber (Marconi and Carcea 2001).

Food gums such as guar gum, locust bean gum and xanthan gum have been used in pasta (Brennan and Tudorica 2007; Manthey and Sandhu 2008, 2009). Especially in the multigrain pasta, gums have been known to help improve the textural and cooking quality of pasta. For example, xanthan gum increased the cooked weight of spaghetti and improved the cooked firmness of flaxseed flour pasta (Manthey and Sandhu 2008).

Nontraditional ingredients often diminish the physical and cooking qualities of pasta. The reduction in quality is widely attributed to 1) interference with gluten network, which weakens the pasta and to 2) competition for available water that results in underhydration of semolina protein and inadequate gluten formation (Marconi and Carcea 2001; Manthey et al 2004; Twombly and Manthey 2006). Particle size and composition of the nontraditional ingredient determines how strongly it competes for moisture. Small particles hydrate quicker than large particles. Protein and fiber tend to compete strongly with water, while intact starch granules and lipid tend to be less competitive (Manthey and Sandhu 2009; Sandhu et al 2012).

Pasta containing high levels of soluble fiber often has white specks that indicate inadequate hydration and the resultant lack of gluten formation. To compensate for inadequate hydration, additional water is often added. However, over-hydration tends to increase the stickiness of ingredients. Fiber ingredients tend to form large aggregates that can stick to metal surfaces and often form bridges that prevent ingredients from entering the extrusion barrel (Manthey and Sandhu 2009).

Hydration during pasta processing can be adjusted to accommodate hydrophilicity of nontraditional ingredient. For example, Manthey et al (2004) reported that a reduced level of hydration for semolina-flaxseed flour was necessary while an increased hydration for semolina-wheat bran mixture was necessary.

Alterations in texture of hydrated materials are a good indication of possible changes in dough strength. Change in dough strength of samples compared to their respective controls, subsequently affects extrusion properties and cooking quality of pasta. Change in the dough strength (i.e very strong dough) makes extrusion extremely difficult and consumes excessive amount of energy, which is undesirable from a manufacturer's point of view (Sandhu et al 2012).

Preliminary results from research conducted to determine the effect of food gums on the quality of pasta made with semolina - nontraditional ingredient blends were very inconsistent. The ease of processing varied with processing day. Some days the hydrated material would adhere to the mixing bowl and form a hard amorphous mass, other days the same blend would hydrate 'properly' and form small uniform aggregates that easily moved into the extrusion barrel. Based on experience with hydration/processing problems when semolina contained wide range of particle sizes, this experiment was designed to determine if processing problems could be reduced by using durum flour. The small particle size inherent with durum flour would favor absorption and promote the hydration of the gluten proteins. Thus this research was conducted to determine if small durum flour particles would be able to compete for moisture with the nontraditional ingredients and food gums and result in more consistent results related to pasta processing.

Materials and Methods

Materials

Semolina and patent durum flour were obtained from the North Dakota Mill and Elevator, Grand Forks, ND. Soy flour and oat flour were obtained commercially from a local grocery store. Xanthan gum (XG) and guar gum (GG) were obtained from Cargill Texturizing

Solutions, Wayzata, MN, USA and locust bean gum (LBG) was procured from Bob's Red Mill Natural Foods Inc., Milwaukee, OR, USA.

Ingredient blends were prepared by fortifying semolina or durum flour with nontraditional ingredients (soy flour and oat flour, 10% w/w) and individual food gum (GG, LBG and XG, 2% w/w). Uniform blends were prepared by mixing ingredients for 5 min using a cross-flow blender (Patterson Kelly, East Stroudsburg, PA, USA). For nontraditional ingredients the 10% was selected because previous research has indicated that 10% substitiuttion of nontraditional ingredient generally has little or no effect on pasta quality (Marconi and Carcea 2001; Zhao et al 2005). It is a reasonable amount to be used commercially. For gums, the 2% represents the maximum amount that would be used. It is the amount that previous research has indicated indicate would have a positive effect on pasta quality (Manthey and Sandhu 2008).

Characterization of Ingredients and Blends

Particle size distributions were determined using a Ro-Tap mechanical shaker (W.S. Tyler, Mentor, OH, USA) with US Standard sieves 30, 40, 60, 80 and 100 (600, 425, 250, 180 and <180 μm, respectively). A 100 g sample was run for 5 min. Each sample was evaluated in triplicate.

Bulk density of individual ingredients was measured using a test weight apparatus (Seedburo Equipment Co., Des Plaines, IL, USA). Material was poured into a standard one-quart container with excess material removed using a leveling stick in the manner used to determine test weight of grain. The weight of material per 0.95 L (1 quart) was converted to g/cm^3.

Individual ingredients were analyzed for moisture, ash and protein contents according to Approved Methods 44-15.02, 08-01.01 and 46-30.01, respectively (AACC International 2010). The conversion factor used to determine protein content was %N x 5.7 for semolina and durum

flour and %N × 6.25 for soy flour and oat flour. Lipid content was determined using a 16 hr Soxhlet extraction with hexane, according to Method Ba 3–38 (AOCS 1998). A digital pH-meter (Corning pH-meter, model 440, at 20^{o}C) was used to determine pH of individual ingredients according to Approved Methods 02-52.01 (AACC International 2010). Blends were analyzed for dough strength as measured by using mixograph (National Manufacturing, Lincoln, NE) according to Approved Method 54-40.02 (AACC International 2010).

Swelling Volume

Swelling volumes of semolina and flour ingredients were determined using Approved Method 52-21.01 (AACC International 2010). Semolina, durum flour, soy flour and oat flour and blends were weighed (0.25 g) into preweighed centrifuge tubes. Distilled water (15 mL) was added to tubes containing sample and mixed on a vortex mixer for 10 sec. Sample tubes were then placed in a 70^{o}C water bath for 4 min, mixed again for 20 sec, placed back in 70^{o}C water bath for 6 min, and then transferred to a boiling water bath for 10 min, placed in cold water for 5 min, and then centrifuged at 3,500 revolutions per min (rpm) for 4 min. Supernatant was carefully removed with a transfer pipette and tubes were weighed. Swelling volume was calculated as follows:

Swelling volume = (Sediment weight)/(Weight of dry sample)

Approximate Water Holding Capacity

Approximate water holding capacity of GG, LBG, and XG were determined according to Approved Method 56-30.01 (AACC International 2010) with some changes in sample size. Samples were weighed (0.45 g than 1g as indicated in the method) on an ‘as-is moisture’ (i.e wet

basis, wb) into a preweighed 50 mL centrifuge tubes (transparent polycarbonate). A small sample size was selected with an aim to get appropriate results due to the strong hydration capacity of food gums. Distilled water was added in small increments and was stirred with glass rod after each addition until sample was thoroughly wetted. Stirring rods were wiped on the sides of the tube. Samples were centrifuged at 2,000 rpm for 1.5 hr and the supernatant removed and discarded. At least three replicates were performed for each sample. The approximate water holding capacity was calculated as:

Approximate water holding capacity (mL/g) = [(Tube weight+Sediment weight)-(Tube weight +0.45)]/0.45

Water Holding Capacity

Gums were weighed into each of four tubes after calculating weight of the material according to the following formula:

Material weight =15/Approximate water holding capacity +1

where 15 is the desired total weight of the sample and water. The volume of water added to the first and second tubes were 1.5 and 0.5 mL more and the volume of water added to the third and fourth tubes were 1.5 and 0.5 mL less than the calculated volume of water (15 - material weight). Contents of the each tube were vigorously mixed with a stirring rod for 2 min and were centrifuged at 2000 rpm for 1.5 hr. Any two adjoining tubes, one with minimum and one with maximum supernatant, represented the theoretical range in which water holding capacity value

would occur. Water holding capacity was presented as true midpoint between volumes of these two tubes (e.g. volume of tube 1 and 2) divided by material weight.

Pasta Processing

Blends (1.3 kg) were hydrated to 32% absorption (wb) with warm distilled water (40^{o}C). The wetted ingredients were mixed at high speed in a Hobart mixer (Hobart Corp., Troy, OH, USA) for 4 min and placed in the mixing chamber of the pasta extruder. Mixing during hydration was done in 3 steps. First, water was added to the ingredients as mixing bowl paddles rotated at 60 rpm; second, mixing continued for 90 sec at 60 rpm; then paddle speed was increased and maintained at 180 rpm for 2 min. Total mixing time was 4 min. This mixing and hydration protocol was applicable only to control samples.

The mixtures were extruded under vacuum as spaghetti using a DeMaCo semicommerical laboratory extruder (DEMACO, Melbourne, FL, USA). Extrusion conditions were: extrusion temperature, 45^{o}C; mixing chamber vacuum, 46 cm of Hg; and screw speed, 25 rpm. The extrusion screw had a length to diameter ratio of 8.5:1, a constant root diameter and uniform pitch of the entire length of the screw.

Mechanical energy (ME; J/s), extrusion rate (ER; g/s), and extrusion pressure (EP; psi) were recorded during the extrusion of each sample. Specific mechanical energy (SME; J/g) was calculated as the ME/ER. The ME required to operate the empty pasta press was subtracted from the ME required to operate the press under load. After extrusion, spaghetti was dried in a laboratory pasta dryer using a high temperature (70^{o}C) drying profile.

Spaghetti Cooking Quality

Spaghetti (10 g) was cooked for 12 min in a glass beaker containing 300 mL boiling water. Cooking was performed using Method 66-50.01 (AACC International, 2010). Cooked

samples were drained for 2.5 min and then weighed to measure cooked weight. Cooking loss (weight of total solids) was measured by evaporating cooking water to dryness in a forced-air oven at 110^{o}C. The cooked samples were measured for their firmness using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA). Firmness was measured by the amount of work (g cm) required to shear five cooked strands of spaghetti using a pasta blade probe attached to the texture analyzer.

Experimental Plan and Statistical Analysis

The experimental design was a randomized complete block with factorial arrangement of nontraditional ingredients and gums, both of which were considered fixed effects. Three replicates were performed on each treatment. Each replicate was extruded on a separate day. Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC, Software). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Results and Discussion

Characterization of Ingredients

Semolina and durum flour had similar percent protein contents (13.1±0.15 and 13.5±0.12), ash contents (0.81±0.01 and 0.77±0.02), and lipid contents (1.3±0.01 and 1.1±0.00), and gluten index values (62 and 70). Soy flour had the greatest percent protein content (35.9±0.46), lipid content (22.1±0.20) and ash content (4.11±0.02), while oat flour had lowest protein content (12.4±0.20), intermediate lipid content (7.6±0.31) and ash content (1.51±0.01).

Swelling volume was greatest with oat flour (10.1±0.21, mL/g), intermediate with semolina (8.8±0.06, mL/g) and durum flour (7.1±0.85, mL/g) and least with soy flour (2.8±0.02,

mL/g). Bulk densities of food gums (Table 1) were similar to those for semolina, durum flour, and oat flour. Bulk density seemed to be inversely related to lipid content and was greatest with semolina (0.71±0.05, g/cm^3), followed by durum flour (0.62±0.01, g/cm^3), oat flour (0.52±0.08, g/cm^3) and least with soy flour (0.42±0.02, g/cm^3).

The particle size distribution is presented in Table 2. Durum flour had the finest particle size with 87% of particles smaller than 250 µm. Soy and oat flours were coarser with 94 and 88% less than 600 µm but greater than 250 µm, respectively. Semolina had higher amount of coarse particles (79% less than 600 µm but greater than 250 µm) compared to durum flour but lower amount than soy and oat flours. . The particles of XG, GG and LBG were 100, 99.2 and 78.1% smaller than 149-µm, respectively.

Dough Properties

Dough properties were evaluated by the mixograph test. Granulation x gum interaction was significant for time-to-peak (Table 3 and Table A1). This was the only interaction that was significant for any of the mixogram parameters tested. Time-to-peak was 1.8 times longer for semolina than for durum flour (Table 3). Time-to-peak is associated with rate of hydration of durum flour or semolina, particularly the endosperm proteins that when hydrated and mixed form the gluten network that is the structure of dough. Small granulation of durum flour has a greater surface area per mass than the large granulation of semolina. Thus, small flour particles hydrate more quickly than do semolina particles and therefore account for lower time-to-peak value.

Locust bean gum did not increase time-to-peak for durum flour (Table 3). However, XG and GG increased time-to-peak with durum flour by 67 and 42%, respectively (Table 3). Guar gums (i.e. GG and XG both at 16.2±0.78 and 16.2±0.20 mL/g and locust bean gum at 9.5±0.1.11 mL/g) (Table 1) were nearly 10 times greater than with semolina, durum flour, soy and oat

Table 1. Physical and chemical characteristics* of gums.

Gum Source[a]	Protein (%)[b]	Ash (%)[b]	BD (g/cm^3)[c]	WHC (mL/g)[c]
XG. Cargill	4.72±0.08	10.8±0.06	0.54±0.01	16.20±0.20
LBG. Cargill	4.40±0.36	0.93±0.11	0.64±0.06	9.49±1.11
GG. Bob's Red Mill	4.21±0.14	0.49±0.02	0.69±0.07	16.20±0.78

*Mean values with standard deviation (Stdev) are presented in the table.
[a]XG-Xanthan gum, [a]LBG-Locust bean gum, [a]GG-Guar gum, [b]reported on 14% mb, [c]BD-Bulk density, [c]WHC-Water holding Capacity.

Table 2. Particle size distribution (%) of semolina, durum flour, soy flour, oat flour and gums.

	Mesh Size, µm					
	600	425	250	180	<180	
Ingredients						Total (g)
Semolina	0	11	68	11	10	100
Durum flour	0	0	12	42	45	99
Soy flour	5	35	59	1	0	100
Oat flour	2	22	68	5	2	99

	Mesh Size, µm						
	600	425	250	180	149	<149	
Gums[a]							Total (g)
XG	0	0	0	0	0	99.7	99.7
LBG	0	0	0.4	2.6	18.6	77.3	99.0
GG	0	0	0	0.2	0.7	98.8	99.6

n=3, XG-Xanthan gum, [a]LBG-Locust bean gum, [a]GG-Guar gum, g-grams.

Table 3. Mean values for granulation x food gum interaction for time-to-peak (sec)*.

Granulation	None	Locust bean gum	Xanthan Gum	Guar Gum
Flour	127b	135b	212b	180b
Semolina	227a	259a	431a	295a
LSD** for interaction =28				

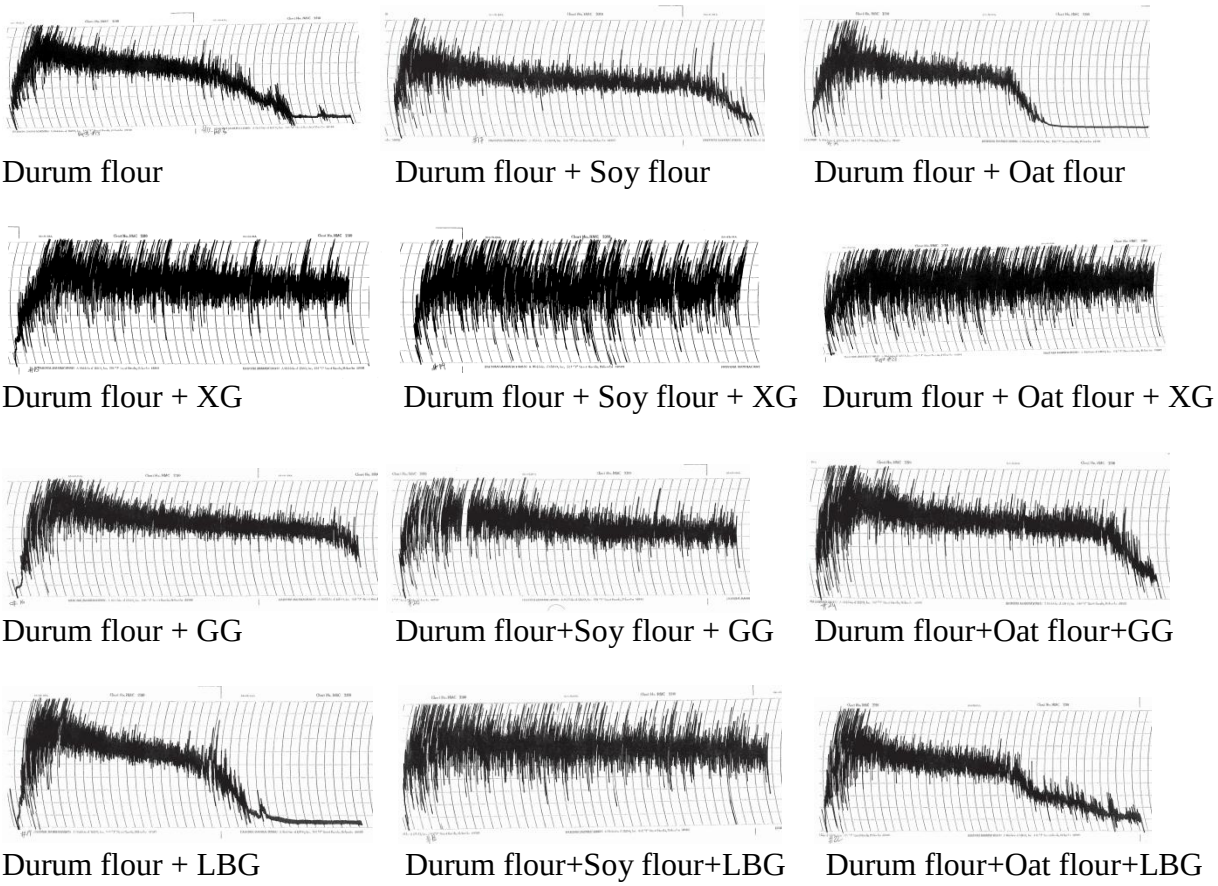
*Mean values followed by same letter in a row or column are not significantly different at *P*=0.05.
**Least significant difference.

flours. Water holding capacity was greatest with soy flour (1.5±0.03 mL/g) and oat flour (1.4±0.04 mL/g) and lowest with semolina (1.1±0.03 mL/g) and durum flour (0.9±0.01 mL/g).

Gums, because of their high hydrophilicity and fine particle size, appeared to delay time-to-peak by reducing the amount of water available to hydrate gluten proteins gums.

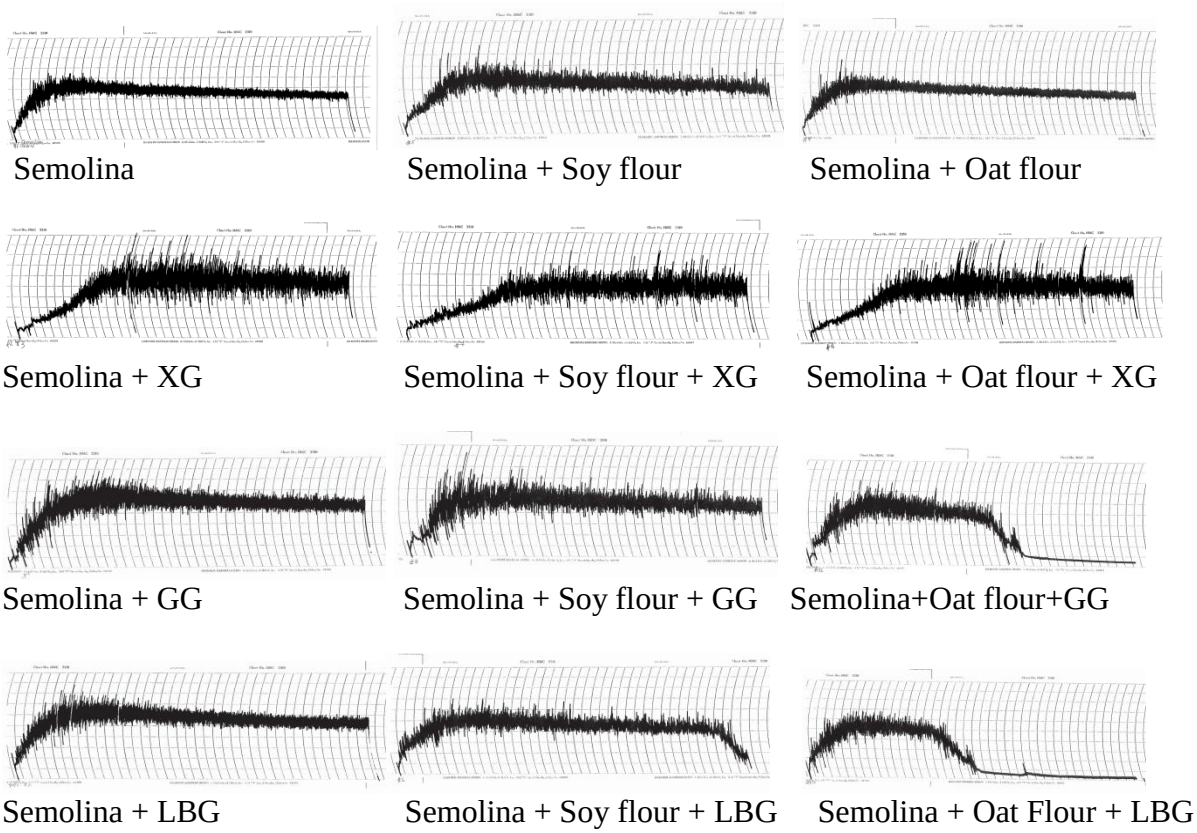
Granulation and gum main effects were significant for all mixogram parameters tested (Table A1). Peak height, peak width, end height and end width were all greater with durum flour than with semolina (Table 4). These results indicate that dough made with durum flour was stronger than dough made with semolina. When mixograms were run for 20 min, the dough made with durum flour began to rapidly breakdown after 12.5 min (Fig. 5). Dough breakdown was not observed with semolina indicating that semolina had greater mixing tolerance than did durum flour (Fig. 6). Thus, dough strength changed overtime and after 20 min dough was stronger with semolina than with durum flour.

Locust bean gum did not significantly increase dough strength as measured by peak height, peak width, end height or end width, compared to dough without a gum (Table 4). Xanthan gum and GG increased all parameters, indicating that they increased dough strength. Peak height, peak width, and end height were similar for XG and GG, however, XG increased end width more than did GG. Stability of dough made with durum flour was improved by XG and GG but not by LBG where rapid breakdown in dough strength began after 11.5 min of mixing (Fig. 5).



XG-Xanthan gum; GG-Guar gum; LBG-Locust bean gum

Fig. 5. Mixograms of durum flour alone and its blend with ingredients and ingredients + gums.



XG-Xanthan gum; GG-Guar gum; LBG-Locust bean gum

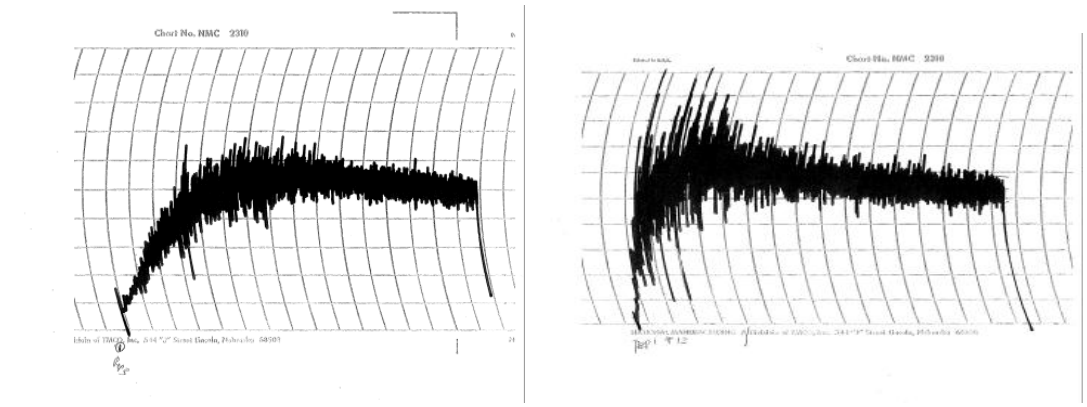
Fig. 6. Mixograms of semolina alone and its blend with ingredients and ingredients + gums.

Table 4. Mean values* for granulation, food gum, and nontraditional ingredient main effect for mixogram parameters.

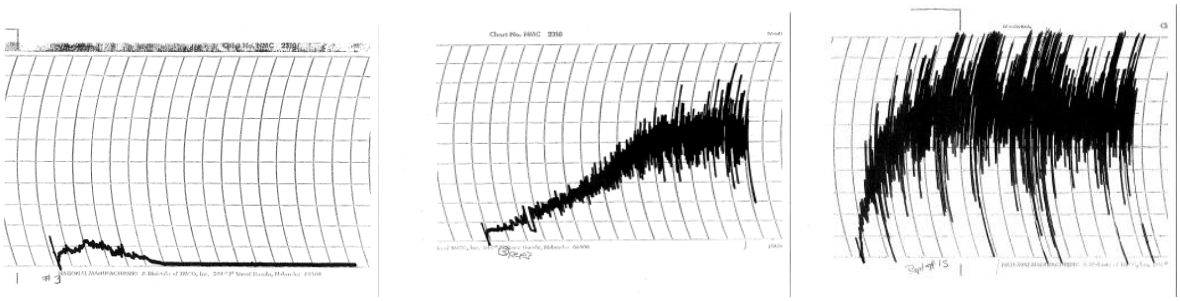
	Peak height (BU)	Peak width (BU)	End height (BU)	End width (BU)
Flour	6.74a	35.1a	5.82a	23.8a
Semolina	5.28b	21.8b	4.98b	16.0b
LSD	0.22	2.4	0.25	2.0
None	5.74	24.8	4.93	14.2
LBG	5.93	25.9	5.18	16.1
Xanthan gum	6.11	32.0	5.76	28.7
Guar gum	6.27	31.2	5.73	21.1
None	6.28	28.5	5.63	19.3
Oat flour	6.00	27.8	5.24	18.4
Soy flour	5.76	29.1	5.33	22.4

*Mean values followed by same letter are not significantly different at P=0.05.
**Least significant difference.

The effect of gums on dough strength was most pronounced with XG. The XG outcompeted the semolina for moisture and thereby reducing the amount of moisture available to hydrate the gluten proteins. The ingredient formulas with XG often became over-hydrated and became sticky causing the developing dough to stick to the metal surface of the mixograph mixing bowl. When this occurred to the extreme, a mixogram failed to form (Fig. 7). The failure to form only occurred with semolina and not with durum flour. The mixogram for durum flour + XG shows that the durum flour was able to compete for water better than the semolina (reliably formed a dough) but the XG still reduced the amount of water available to hydrate the durum flour dough, as seen by the notable increase in dough strength. Water acts as a plasticizer in dough systems, whereby dough strength increases as available moisture decreases (Manthey and Sandhu 2009).



Semolina Durum flour



Semolina + XG Semolina + XG Durum Flour + XG

Fig. 7. Mixogram showing dough strength of durum flour vs semolina and durum flour + XG vs semolina + XG.

Nontraditional ingredient main effect was significant for peak height, end height and end width (Table 4). Oat flour reduced peak height and end height and soy flour reduced peak height and end width. These results indicate that both oat flour and soy flour reduced dough strength but affected dough somewhat differently. Soy flour improved dough stability of durum flour (Fig. 5). Rapid breakdown in dough made with durum flour and soy flour occurred after 16.5 min compared to 12.5 min for dough made only with durum flour. Oat flour did not affect stability of dough made with durum flour (Fig. 5).

Gums affected the stability of dough made with blends of nontraditional ingredient and either durum flour or semolina. For semolina-oat flour blends, dough stability declined sharply

after 11.5 min and 8.5 min in blends contained GG and LBG, respectively (Fig. 5 and 6). For the durum flour-soy flour blends, all gums increased dough stability. For durum flour-oat flour blends, XG and GG improved dough stability while locust bean gum had little effect (Fig. 5).

Difference in performance of nontraditional ingredients with semolina and durum flour could be related to larger difference between their particle sizes. Soy flour and oat flour had particle size more similar to semolina but very large compared to durum flour (Table 2). Great difference in particle size could affect rate of hydration and subsequent dough strength.

Ryan et al (2002) reported that negative effects associated with wheat-soy dough are primarily due to lack of interactions between soy and wheat proteins. Factors that might be responsible for the lack of interaction between soy and wheat proteins or starch are still unknown.

Pasta Processing

Hydration of Blends

With all blends, the length of mixing time varied depending upon whether blend contained semolina or durum flour, soy flour or oat flour and GG, LBG or XG (Tables 5 and 6). When a sample appeared to be properly hydrated, further mixing was stopped since over-mixing tended to deteriorate texture of the hydrated mass. Deteriorated texture refers to when hydrated ingredients became sticky and accumulated on the sides of the mixing bowl.

Semolina/Durum Flour + Gums

Observations made with semolina + XG blend (Table 5) are attributed to the nearly 10 times greater water holding capacity of XG (16.2±0.20 mL/g vs semolina at 1.1±0.03 mL/g) and its smaller particle size distribution compared to semolina (Table 2). As a function of high water holding capacity and smaller particle size, XG particles appeared to quickly hydrate and became sticky leaving surrounding semolina particles underhydrated. Sticky overhydrated XG particles

Table 5. Description of the hydration and mixing of semolina alone and with nontraditional ingredients and gums.

Semolina			
Variables	**Mixing time (min) at 60 rpm**	**180 rpm**	**Description of hydration and mixing**
Semolina (Se)	2	2	Small aggregates (3 to 5 mm dia.) Uniform distribution of fine hydrated particles.
Se+XG	1	-	Hydration occurred rapidly. Mixing >1 min resulted in accumulated hydrated mass along walls of bowl. Hydrated material was extremely hard and tough amorphous mass, which appeared wet. Large hard pieces were difficult to extrude and had a tendency to bridge and block the flow of material into the extruder barrel.
Se+GG	2	2	Hydrated Se+GG looked similar to hydrated semolina control.
Se+LBG	2	2	Hydrated Se +LBG appeared dry. Semolina + gums (XG, GG and LBG), all had different appearance after hydration.
Se+OF	2	2	Blend looked dry. Additional 15 mL water was added to the blend for better hydration. Without extra water added, extruded spaghetti was brittle and fragile.
Se+OF+XG	1	-	Hydrated blend looked wet and the dough formed was weak. Freshly extruded spaghetti tended to break and fall off the drying rods.
Se+OF+GG	2	2	Very dry texture. Additional 25 mL water was added to allow a dough to form during extrusion
Se+OF+LBG	2	2	Dry initial texture. Additional 15 mL water was added for proper dough formation. The dough formed with Se+OF+LBG/GG blends were weak since freshly extruded spaghettis were brittle to touch.
Se+SF	1	-	Hydrated blend appeared wet and sticky. Fresh spaghetti was firm and strong.
Se+SF+XG	1	-	Similar as above (Se+SF) Similar as above
Se+SF+GG	2	2	Both SE+SF+GG and Se+SF+LBG behaved similarly. Both hydrated blends initially looked wet. But by the end of mixing, blends appeared to be appropriately hydrated
Se+SF+LBG	2	2	

Se-semolina, XG-xanthan gum, GG-guar gum and LBG-locust bean gum, rpm-revolutions per minute.

Table 6. Description of the hydration and mixing of durum flour alone and with nontraditional ingredients and gums.

Durum flour			
Variables	**Mixing time (min) at 60 rpm**	**180 rpm**	**Description of hydration and mixing**
Durum flour (DF)	2	2	Distribution of both fine hydrated particles and aggregates of small-soft particles, which broke easily when mixed.
DF+XG	1	1	Mixing time longer than 2 min, settled hydrated mass on walls of the mixing bowl. Hydrated agglomerates were soft and broke easily when mixed with a ladle.
DF+GG	2	2	Similar appearance and tactile assessment as the DF control
DF+LBG	2	2	Similar appearance and tactile assessment as the DF control
DF+OF	2	2	Similar appearance and tactile assessment as the DF control
DF+OF+XG	1	-	Similar appearance and tactile assessment as the DF control
DF+OF+GG/LBG	2	2	Similar appearance and tactile assessment as the DF control
DF+SF	1	-	Similar appearance and tactile assessment as the DF control
DF+SF+XG	1	-	Similar appearance and tactile assessment as the DF control
DF +SF+GG/LBG	1	2	Similar appearance and tactile assessment as the DF control

DF-durum flour, XG-xanthan gum, GG-guar gum and LBG-locust bean gum, rpm-revolutions per minute.

coated the underhydrated semolina particles and collectively formed a hard mass that adhered to the sides of the mixing bowl. Uneven hydration prevented uniform hydration of semolina particles and subsequent development of gluten network. Weak gluten network was evident from the fragile and brittle nature of freshly extruded spaghetti. These results support those of mixograph, which showed that XG increased the apparent dough strength of the semolina. Observations made during the hydration and mixing of durum flour + XG blends, support the mixogram results of durum flour + XG blends, that durum flour competed for water better than the semolina.

Semolina/Durum Flour + Oat Flour + Gums

Observations suggest that the oat flour out competed the semolina for moisture, preventing adequate gluten formation. Observations for semolina + oat flour + XG blend are

attributed to the XG becoming overhydrated and coating the semolina and oat flour (Table 6). The semolina was underhydrated and poor gluten matrix was formed. Observations made with semolina + oat flour + LBG or GG blends support mixogram results, whereas in semolina-oat flour blends, dough stability declined sharply after 11.5 min and 8.5 min (Fig. 6 and Table 5).

Semolina/Durum Flour + Soy Flour + Gums

Observations for semolina + soy flour and semolina + soy flour + XG blend could be due to difference in the particle size distribution (Table 2) and swelling power of semolina compared to soy flour. Observations made with durum flour + soy flour/oat flour and durum flour + soy flour/oat flour + XG/GG and LBG blends suggest that fortification of ingredients such as soy flour or oat flour and gums, affect the rate of hydration of durum flour particles (Table 6). With semolina, the ingredients affected both mixing time and texture of the hydrated mass, while with durum flour, they affected only mixing time (Tables 5 and 6). Difference in performance of nontraditional ingredients with semolina and durum flour could be related to larger difference between their particle sizes. Soy and oat flour had particle size more similar to semolina but very large compared to durum flour (Table 2). Differences in particle size could affect rate of hydration and subsequent dough strength (Manthey et al 2004).

Physical Quality

Freshly extruded spaghetti made with semolina was firm and smooth while spaghetti made with durum flour alone was soft, very smooth to touch and uniform in appearance. Semolina + XG spaghetti was firm and brittle to touch when hung on rods for drying. In contrast spaghetti made from durum flour + XG or LBG or GG was firm and smooth. In general, durum flour spaghetti, fortified with ingredients and gums had a uniform appearance and a smooth

texture to the touch while spaghetti made from semolina with fortified ingredients and gums was brittle and not smooth to touch.

Cooking Quality

Granulation x gum interaction was significant for cooked weight of spaghetti and granulation x nontraditional ingredient interaction was significant for cooked weight and cooking loss of spaghetti (Table A2). Among gums, XG increased the cooked weight most in durum flour spaghetti (by 4.3%) compared to durum flour spaghetti without gums (Table 7). Xanthan gum and GG, both increased cooked weight in semolina spaghetti by 4.5 and 2% respectively, while LBG had cooked weight similar to semolina spaghetti without gums (Table 7). Results indicate that XG increased cooked weight more in semolina than in durum flour. Brennan and Tudorica (2007) reported that XG has been shown to improve the cooked weight of pasta and noodle products.

Nontraditional ingredients decreased cooked weight in durum flour spaghetti. It was decreased by 1.3% with oat flour and 4.2% with soy flour in durum flour compared durum flour spaghetti without nontraditional ingredients (Table 7). Cooked weight was similar for semolina + oat flour spaghetti and semolina spaghetti without nontraditional ingredients. Soy flour decreased cooked weight with semolina by 4.7% (Table 7).

Oat flour increased cooking loss of spaghetti made with durum flour by 9.1% but had no affect in semolina compared to durum flour and semolina spaghetti without nontraditional ingredients respectively (Table 7). Soy flour increased cooking loss of pasta made with durum flour and semolina by 18.8 and 14% respectively (Table 7).

Table 7. Granulation, food gum and nontraditional ingredient affect on cooking quality. Parameters*.

Parameter	Firmness, gcm	Cooked weight, %		Cooking loss, %	
		Durum flour	Semolina	Durum flour	Semolina
Granulation					
Durum flour	26.6b	-	-	-	-
Semolina	27.4a				
LSD**	-				
Food gum					
None	24.9b	30.3 b	30.5 c	-	-
Guar gum	25.0b	30.1 bc	31.1 b	-	-
Locust bean gum	25.2b	30.0 cd	30.5 c	-	-
Xanthan gum	32.7a	31.6 a	31.9 a	-	-
LSD**	-	0.3			
Nontraditional ingredient					
None	28.4a	311 a	316 a	6.6 c	5.7 b
Oat flour	26.1b	307 b	316 a	7.2 b	5.8 b
Soy flour	26.4b	298 c	301 b	7.8 a	6.5 a
LSD**	-	2		0.2	

*Mean values followed by same letter are not significantly different at P=0.05.
**LSD-Least significant difference.

Oat flour, with its high level of β-glucan (Doehlert and Moore 1997) and high lipid containing soy flour, diluted durum flour's ability to absorb water, which reduced overall cooked weight of the blend relative to durum flour alone. Less proximity in particles size, lead to greater breakdown of matrix during the cooking process thus explaining higher cooking losses. Results also indicate that soy flour decreased cooked weight more in semolina than durum flour. It reflects higher water binding ability (refers to swelling volume) of durum flour than semolina.

Granulation, gum and nontraditional ingredient main effect were significant for cooked firmness of spaghetti (Table A2). Spaghetti made with semolina had higher cooked firmness than with durum flour (Table 7). Xanthan gum increased cooked firmness of spaghetti compared to

GG, LBG and spaghetti without gums (Table 7). Nontraditional ingredients decreased cooked firmness of spaghetti compared to spaghetti without nontraditional ingredients (Table 7). Higher cooked firmness related with semolina explains its stronger dough strength relative to durum flour (Fig 2 and 3). Manthey and Sandhu (2008) reported that XG (2% w/w) increased cooked firmness in spaghetti made with semolina + flaxseed flour (15% w/w). Edwards et al (1995) reported similar findings where XG improved pasta firmness characteristics of wholewheat pasta. Nontraditional pastas often have reduced physical and cooking qualities (Marconi and Carcea 2001; Manthey et al 2004; Twombly and Manthey 2006). Protein in oat flour and soy flour are globulins and differ greatly in structure from the prolamin proteins found in semolina. Oat and soy proteins are not able to form viscoelastic dough. Their presence in semolina acts to dilute or disrupt gluten network, which can result in decline in physical strength and in cooked firmness and increase in cooking loss. Ingredients containing high levels of fiber often result in reduced cooked firmness. The reduction in cooked firmness has been attributed to high water holding capacity of fiber which contributes to softening of cooked pasta.

Conclusion

Characteristics and particle size distribution of semolina, durum, soy and oat flours were different relative to each other. Proximate analysis and particle size distribution of gums varied among each other and relative to semolina, durum, soy and oat flours. Granulation, gums and nontraditional ingredients had major impact on dough properties. Food gums had a bigger impact on time-to-peak with semolina than when with durum flour. Semolina had hydration time that was 1.8 times longer than durum flour. Dough was stronger with semolina than with durum flour in 20 min mixogram. Stability of dough made with durum flour was improved by XG and GG but not by LBG. The effect of gums on dough strength was most pronounced with XG. Both oat

flour and soy flour reduced dough strength but affected dough somewhat differently. Oat flour reduced peak height by 4.5% and end height by 6.9% and soy flour reduced peak height by 8.3% and end width by 5.3% and improved dough stability of durum flour (increased peak width-2.1% and end width-16.0%).

Results for the effect of gums and nontraditional ingredients on dough strength of semolina and durum flour were reflected in hydration properties of blends, physical quality of spaghetti and cooking quality. They indicate the significance of dough quality characteristics in preparation of pasta. Overall, nontraditional pasta made with semolina had better quality over nontraditional pasta made with durum flour. There is no doubt that gums performed better and had much pronounced affect in durum flour than they had in semolina. It indicates importance of close proximity in the particle size of durum flour blends, which tended to enhance performance of particles during the hydration and dough making process. However, durum flour nontraditional pasta was associated with higher cooking losses compared to semolina nontraditional pasta, which is undesirable from pasta quality perspective.

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PAPER 2. PHYSICOCHEMICAL PROPERTIES OF COMMERCIAL GUAR GUM AND THEIR EFFECT ON PROCESSING AND COOKING QUALITY OF NONTRADITIONAL PASTA

Abstract

The physicochemical properties of three different commercial sources of guar gum (GG) were determined and its subsequent effect on the processing and cooking quality of pasta containing nontraditional ingredients characterized. Durum flour that was procured from commercial durum wheat was fortified with nontraditional ingredients (soy flour or oat flour, 10% w/w) and with GG (2% w/w). Hydrated ingredients were extruded as spaghetti, which was dried using a high temperature drying cycle (70^{o}C). Ash content, bulk density, particle size distribution, water holding capacity, the molecular size, and viscosity of GG at three different concentrations (0.2, 0.3 and 0.4%) in distilled water varied among different vendors. Mixograms indicated that GG increased the dough strength of durum flour and the extent of the increased strength varied with vendor. The effect of GG and the effect of commercial source of GG on dough strength were manifested in differences in extrusion rate, where strongest dough had the greatest extrusion rate. Extrusion rate was less with GG1 (GG from vendor 1, 3.5 g/sec) and GG3 (GG from vendor 3, 3.4 g/sec) than with GG2 (GG from vendor 2, 3.6 g/sec) ($LSD_{0.05}$=0.16). Guar gum, regardless of vendor, had no effect on the cooking quality of pasta.

Introduction

Galactomannan gums, such as GG are obtained from the ground endosperm of seeds from an annual plant commonly called cluster bean (*Cyamopsis tetragonolobus* L.) (Fox 1992). Galactomannan gums are natural, water-swelling, non-toxic and non-ionic polysaccharides. They consist of a linear chain of (1,4)-linked *β*-D-mannopyranosyl backbone, substituted with (1,6)-linked α-D galactopyranosyl units. Guar gum normally has a mannose to galactose (Man/Gal) ratio of 2:1 (Fox 1992). Compared to other galactomannans, GG has a relatively high water solubility and is a better stabilizer due to its high number of galactose branch points (Fox 1992).

Gums, such as GG and LBG are commonly used in food applications, including dough systems. There is an increasing trend in fortification of extruded cereal products with galactomannan gums (Parada et al 2010). Inclusion of galactomannan gums in pasta/noodle systems is based primarily on their property to thicken and stabilize food matrixes by binding water or used as fiber (Brennan and Tudorica 2008; Parada et al 2010). Guar gum has been reported to favorably interact with gluten proteins and increase dough stability (Linlaud et al 2009, 2011). Yu and Ngadi (2006) reported that GG enhanced the cohesion and mechanical strength (rheological properties) of instant fried noodles.

Traditional pasta made from semolina is low in fiber, minerals, and vitamins. Semolina protein is low in essential amino acids, lysine and methionine. To improve nutritional quality, nontraditional or functional ingredients, such as oat flour and soy flour, have been used to fortify pasta products that are often referred to as functional pastas (Cleary and Brennan 2006; Twombly and Manthey 2006; Baiano et al 2011; Mitra et al 2012). Oat flour is rich in dietary fiber, particularly, β-glucan, and its protein is more digestible than is protein from semolina. Soy protein is rich in the essential amino acids arginine, leucine, lysine, phenylalanine, and valine

(Twombly and Manthey 2006). Soy flour also contains nutraceutical compounds such as isoflavones.

Functional pastas often have reduced physical and cooking qualities (Marconi and Carcea 2001; Manthey et al 2004; Twombly and Manthey 2006). Protein in oat flour and soy flour are globulins and differ greatly in structure from the prolamin proteins found in semolina. Oat and soy proteins are not able to form viscoelastic dough. Their presence in semolina acts to dilute or disrupt gluten network, which can result in decline in physical strength and in cooked firmness and increase in cooking loss. Ingredients containing high levels of fiber often result in reduced cooked firmness. The reduction in cooked firmness has been attributed to high water holding capacity of fiber which contributes to softening of cooked pasta.

Food gums have been evaluated for their ability to improve the physical and cooking qualities of functional pastas. Gums can affect dough properties by interacting with protein and starch which affect gluten network and starch pasting properties. Dough strength could be diminished if gums interfered with gluten development by blocking formation of disulfide bonds. Linlaud et al (2011) reported that protein in doughs with gums was more unfolded and conformation of disulfide bonds was different from dough without gums. Dough strength is further affected by the hydration and water binding properties of gums. Water acts as a plasticizer causing dough strength to decrease with increased available water (Manthey and Sandhu 2009). Gums decrease the amount of available water thus, resulting in increased dough strength (Manthey and Sandhu 2008).

Inclusion of food gums in the formulation of extruded products has resulted in changes in the physical characteristics such as texture and cooking quality of pasta (Manthey and Sandhu 2008; Bárcenas et al 2009; Linlaud et al 2009; Aravind et al 2012). The extent of the effect was

dependent on the type and level of gum. Brennan and Tudorica (2007) evaluated the effect of seven non-starch polysaccharides, including GG, on cooking quality of fresh spaghetti. They reported that cooking loss was increased by all non-starch polysaccharides but XG. They also reported that pasta firmness decreased, elasticity decreased, and stickiness increased with increased GG concentration.

Similar to other crops, yield and quality of cluster bean (GG) is affected by cultivar and environment (Kays et al 2006; Liu et al 2007; Pathak et al 2010). For manufacturing GG, commercial suppliers procure their raw material from different parts of the world. This brings variation among sources of gum (Pollard et al 2008). Depending upon the source, variation in GG physicochemical properties and its effectiveness to perform in a food system could exist. Daas et al (2000) evaluated the galactose distribution in 10 GG samples obtained from five vendors and found that although all GG's tested had blockwise distribution of galactose, there were modest variations in mannose substitution and degree of blockiness. Degree of blockiness refers to the number of non-substituted mannose residues liberated during the enzymatic digestion using endo-Mannanase of *Aspergillus niger*. It is expressed as percentage of the total number of non-substituted resides present per gram of glactomannan.

Commercially available GG contains protein, mono, oligo, and polysaccharide contaminants, and minerals (Cunha et al 2007). Particle size and purity of GG can affect its biological applications. Particle size affects hydration rate, which could affect action in the gut (Wang et al 2003). The biological activity of GG depends on its potential to increase the viscosity of digesta in the stomach and small intestine (Brennan et al 1996; Slaughter et al 2002). The degree of viscosity generated in the gastrointestinal tract by the GG galactomannan is

determined by the molecular weight and concentration of the polymer, that affects whether the polymer hydrates to form molecular dispersion (Ellis et al 1996, 2001).

Degree and rate of hydration affects the functionality of GG. The effects of particle size and molar mass on hydration and functional properties of GG have been investigated by Wang et al (2003, 2006, 2008). Abundant literature exists where they have studied quality and functionality of gums from one source. There has been very limited information on properties, quality characteristics and functionality of the gums from different sources. Also, no literature was found that studied the effect of different commercial sources of GG on the processing properties and cooking quality of pasta containing nontraditional ingredients. Therefore, this study was undertaken with an aim to compare and characterize GG from different vendors of food grade gums and their subsequent affect on the processing and cooking quality of pasta containing nontraditional ingredients.

Materials and Methods

Materials

Commercial patent durum flour was obtained from the North Dakota Mill and Elevator, Grand Forks, ND. Soy flour and oat flour were obtained commercially from a local grocery store. Guar gum was procured from three different vendors (Bob's Red Mill Natural Foods Inc., Milwaukee, OR, USA; Sigma-Aldrich, St. Louis, MO, USA; and Tic-Gums, White Marsh, MD, USA). Dextran standards were purchased from Sigma Aldrich Corp. (St. Louis, MO). The gel permeation grade dextran standard molecular weights were as follows: 48,600, 147,600, 273,000, 409,800, 667,800, 1.4 million, and 5–40 million Da.

Flour blends were prepared by fortifying durum flour with nontraditional ingredients (oat flour and soy flour, 10% w/w) and GG (2% w/w). Uniform blends were prepared by mixing

ingredients for 5 min using a cross-flow blender (Patterson Kelly, East Stroudsburg, PA, USA). The 10% level of nontraditional ingredients were selected because previous research had indicated that 10 % substitution of nontraditional ingredient generally has little or no effect on pasta quality (Marconi and Carcea 2001; Zhao et al 2005). It is a reasonable amount to be used commercially. For gums, the 2% represents the maximum amount that would be used. It is the amount that previous researchers had indicated would have a positive effect on pasta quality (Manthey and Sandhu 2008).

Characterization of Ingredients and Flour Blends

Particle size distributions were determined using a Ro-Tap mechanical shaker (W.S. Tyler, Mentor, OH, USA) with US Standard sieves 30, 40, 60, 80 and 100 (600, 425, 250, 180 and <180 μm, respectively). A 100 g sample was run for 5 min. Each sample was evaluated in triplicate.

Bulk density (BD) of individual ingredients was measured using a test weight apparatus (Seedburo Equipment Co., Des Plaines, IL, USA). Material was poured into a standard one quart container with excess material removed using a leveling stick in the manner used to determine test weight of grain. The weight of material per 0.95 L (1 quart) was converted to g/cm^3.

Individual ingredients were analyzed for ash, moisture, and protein contents according to Approved Methods 08-01.01, 44-15.02, and 46-30.01, respectively (AACC International 2011). The conversion factor used to determine protein content was %N x 5.7 for durum flour and %N × 6.25 for soy flour and oat flour, and GG. Lipid contents were determined using a 16 hr Soxhlet extraction with hexane, according to Method Ba 3–38 (AOCS 1998). A digital pH-meter was used at 20^oC to determine pH of durum flour, soy flour and oat flour according to Approved Methods 02-52.01 (AACC International 2011). Blends were analyzed for dough strength as

measured by mixograph (National Manufacturing, Lincoln, NE, USA) according to Approved Method 54-40.02 (AACC International 2011).

Swelling Volume

Swelling volume of durum flour ingredients were determined using Approved Method 52-21.01 (AACC International 2010). Durum, soy and oat flour and blends were weighed (0.25 g) into pre-weighed centrifuge tubes (15 mL). Distilled water (15 mL) was added to tubes containing sample and were mixed on a vortex mixer for 10 sec. Sample tubes were then placed in a 70^{o}C water bath for 4 min, vortex mixed for 20 sec, placed back in 70^{o}C water bath for 6 min, then transferred to a boiling water bath for 10 min, placed in cold water for 5 min and then centrifuged at 3,500 revolutions per minute (rpm) for 4 min. Supernatant was carefully removed with a transfer pipette and tubes were weighed. Swelling volume was calculated as follows:

$$\text{Swelling volume} = (\text{Sediment Weight})/(\text{Weight of dry sample})$$

Approximate Water Holding Capacity

Approximate water holding capacities of durum, soy and oat flour were determined according to Approved Method 56-30.01 (AACC International 2011). For GG, method 56-30.01 (AACC International 2011) was used with some modifications as described below. Samples were weighed (0.45 g than 1 g as indicated in the method) on an 'as-is moisture' (i.e., wet basis, wb) into a pre-weighed 50 mL centrifuge tubes (transparent polycarbonate). A small sample size was selected with an aim to get appropriate results due to the strong hydration capacity of gum. Distilled water was added in small increments and was stirred with glass rod after each addition until sample was thoroughly wetted. Stirring rods were wiped on the sides of the tube. Samples

were centrifuged at 2,000 rpm for 1.5 hr and the supernatant removed and discarded. At least three replicates were performed for each sample. The approximate water holding capacity was calculated as:

Approximate water holding capacity (mL/g) =

[(tube weight+sediment weight)-(tube weight +0.45)]/0.45

Water Holding Capacity

Durum, soy and oat flour and gums were weighed into each of four tubes after calculating weight of the material according to the following formula:

Material weight =15/ approximate water holding capacity +1,

where 15 is the desired total weight of the sample and water. The volume of water added to the first and second tubes were 1.5 and 0.5 mL more, respectively, and the volume of water added to the third and fourth tubes were 1.5 and 0.5 mL less, respectively, than the calculated volume of water (15 - material weight). Contents of the each tube were vigorously mixed with a stirring rod for 2 min and were centrifuged at 2,000 rpm for 1.5 hr. Any two adjoining tubes, one with minimum and one with maximum supernatant, represented the range in which water holding capacity value would occur. Water holding capacity was presented as midpoint between volumes of these two tubes (e.g. volume of tube 1 and 2) divided by material weight.

Physicochemical Characterization of Guar Gum

Stock solutions (0.5%, w/v) of GG, obtained from three different commercial sources were prepared. Weight of the gums was calculated on an 'as-is moisture' (i.e., wet basis, wb). Guar gums from varied sources were weighed (1.25 g) and were thoroughly dispersed in 250 mL volumetric flask containing 200 mL of doubly distilled water (ddH_2O) followed by addition of Sodium azide salt (0.2% wt in 250 mL ddH_2O). Sodium azide salt was added with an aim to minimize the microbial growth. Gums were allowed to hydrate overnight at 4^oC. Gum solutions were then continuously stirred at slow speed with a magnetic stirrer for 2 hr at ambient temperature. Volume was adjusted to 250 mL using ddH_2O and was heated for 30 min at 75^oC in a water bath to hydrate gums completely. Gum solutions were centrifuged at 2,000 rpm for 1.5 hr to separate the insoluble particles. Clear supernatant was collected and insoluble particles were oven dried at 105^oC for 7 hr. Upon cooling, dried weight was recorded. Then difference in the weight of original gum sample and dried gum residue was determined, which was used to calculate true concentration of the stock solution as follows:

True Concentration = [(original gum wt – dried gum residue wt)/volume of stock solution]*100

Stock solutions were stored at 4^oC to minimize bacterial growth.

<u>High Performance Size Exclusion Chromatography (HPSEC)</u>

The initial stock solutions of GG samples from different sources were diluted 10 times with ddH_2O. Diluted solution was heated to 50^oC, and stirred for 1 hr, and filtered warm through 0.45 µm syringe filters (nylon). A 20 µL volume of gum sample was injected into the Agilent HPLC 1200 series high-performance liquid chromatograph (Agilent Technologies, Wilmington,

DE). Waters Ultrahydrogel linear column (7.8 mm x 300 mm) was used to separate the polysaccharides. HPLC grade water was used as the mobile phase solvent at a flow rate of 0.4 mL/min at a constant at 40^{o}C. An Agilent refractive index detector and PC with ChemStation (HP ChemSation for LC Rev. A.04.01) were used for control and integration. Samples were run in triplicate. Weight-averaged molecular weights were calculated using a series of gas permeation chromatography-grade dextrans.

Monosaccharide Composition

A method described by Blakeney et al (1983) was used to determine monosaccharide composition of GG samples. Method involved simple and rapid preparation of alditol acetates for monosaccharide analysis. The alditol acetate samples were analyzed on a Hewlet Packard 5890 series II Gas Chromatograph (GC) system with a Flame Ionization Detector (FID) (Agilent Technologies, Inc. Santa Clara, CA). Supelco SP-2380 fused silica capillary column (30 m×0.25mm×0.2 μm) (Supelco Bellefonte, PA) was used to separate monosaccharides. The system parameters were as follows: injector and detector temperatures of 230°C and 250°C, respectively, flow rate of (mobile phase gas, Helium) 0.8 mL/min, flow pressure 82.7 kPa and an oven temperature of 100°C.

Rheological Measurements

The volume (v_1) of the stock solution required to prepare GG solutions (0.2%, 0.3% and 0.4%, w/v) was calculated using formula:

$$(m_1v_1=m_2v_2),$$

where m_1 is true concentration of the stock solution, m_2 is the required concentration of the solution and v_2 is the final volume of the solution that has to be made. Viscosity of GG samples from different commercial sources were analyzed at three different concentrations (0.2 %, 0.3 % and 0.4 % w/v) using a Stresstech controlled stress/strain rheometer (ATS Rheosystems, Bordentown, NJ) with parallel plates. The solutions were pipetted (0.3 mL) between the plates and evenly spread out and the gap was adjusted to 0.5 mm. A constant shear rate (1/s) of 1.006, 1.589, 2.513, 3.981, 6.304, 10, 15.83, 25.13, 39.55, 63.09, 100, 158.5, 251.2, 397.3, and 631 was used for analysis and the samples were run at 20°C. Samples were run in triplicate. Values obtained were the average of triplicates that were used to determine final viscosity per sample.

Pasta Processing

Blends (1.3 kg) were hydrated to 32% (wb) with warm distilled water (40^{o}C). The wetted ingredients were mixed at high speed in a Hobart mixer (Hobart Corp., Troy, OH, USA) for 4 min and placed in the mixing chamber of the pasta extruder. Mixing during hydration was done in 3 steps. First, water was added to the ingredients as mixing bowl paddles rotated at 60 rpm; second, mixing continued for 90 sec at 60 rpm; then paddle speed was increased and maintained at 180 rpm for 2 min. Total mixing time was 4 min.

The mixtures were extruded under vacuum as spaghetti using a DeMaCo semicommerical laboratory extruder (DEMACO, Melbourne, FL, USA). Extrusion conditions were: extrusion temperature, 45^{o}C; mixing chamber vacuum, 46 cm of Hg; and screw speed, 25 rpm. The extrusion screw had a length to diameter ratio of 8.5:1, a constant root diameter and uniform pitch of the entire length of the screw.

Mechanical energy (ME; J/s), extrusion rate (ER; g/s), and extrusion pressure (EP; psi) were recorded during the extrusion of each sample. Specific mechanical energy (SME; J/g) was

calculated as the ME/ER. The ME required to operate the empty pasta press was subtracted from the ME required to operate the press under load. After extrusion, spaghetti was dried in a laboratory pasta dryer using a high temperature (70^{o}C) drying profile.

Spaghetti Color and Cooking Quality

Color of the spaghetti was determined by measuring CIE L, *a*, and *b* values using a Minolta CR-310 Colorimeter (Minolta Corp., Ramsey, NJ). L-value represents brightness; *a*-value represents redness when positive and greenness when negative; and *b*-value represents yellowness when positive and blueness when negative.

Spaghetti (10 g) was cooked for 12 min in a glass beaker containing 300 mL boiling water. Cooking was performed using Method 66-50.01 (AACC International, 2010). Cooked samples were drained for 2.5 min and then weighed to measure cooked weight. Cooking loss (weight of total solids) was measured by evaporating cooking water to dryness in a forced-air oven at 110°C. The cooked samples were measured for their firmness using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA). Firmness was measured by the amount of work (g cm) required to shear five cooked strands of spaghetti using a pasta blade probe attached to the texture analyzer.

Experimental Plan and Statistical Analysis

The experimental design was a randomized complete block with factorial arrangement for fixed effects of nontraditional ingredients and hydrocolloid sources. Three replicates were performed on each treatment. Each replicate was extruded on a separate day. Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC, Software). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Results and Discussion

Characterization of Commercial Guar Gums

Physical Properties of Commercial Guar Gums

Bulk density and water holding capacity significantly ($LSD_{0.05}$ = 0.02 and 0.3, respectively) differed among the commercial sources of GG. Bulk density was greatest with GG2 (0.72 g/cm^3), intermediate with GG3 (0.69 g/cm^3), and least with GG1 (0.66 g/cm^3). Overall, bulk density of GG (0.69 g/cm^3) was greater than that of durum flour (0.62±0.01 g/cm^3), oat flour (0.52±0.08 g/cm^3), or soy flour (0.42±0.01 g/cm^3). Guar gum 2 and GG3 had greater water holding capacities (16.2 mL/g) than did GG1 (15.2 mL/g) ($LSD_{0.05}$= 0.3). Variation in water holding capacity might reflect dissimilarities in the distribution of galactose that has been found to occur among samples of GG from different vendors (Daas et al 2000). In this study, water holding capacity of GG's from different vendors could also vary due to variation in the number galactose branch points available for interaction with water molecules. The water holding capacity of GG's (GG1 = 15.2 mL/g, GG2 and GG3 = 16.2 mL/g) were over 10 fold greater than that for durum flour (0.9±0.01 mL/g), oat flour (1.4±0.04 mL/g), or soy flour (1.5±0.03 mL/g).

Particle size distribution varied among different commercial sources of GG. Guar gum 1, GG3 and GG2 had 99.5%, 98.8% and 91% of their particles smaller than 149 μm, respectively. Guar gum 3 and GG2 had 0.9% and 9.0% particles bigger than 149 μm, respectively. Guar gum 2 had the greatest amount of coarse particles. Irrespective of the commercial source, all GG had smaller particles compared to durum, oat, and soy flours (Table 8).

Table 8. Mean values of particle size distribution (%) of durum, soy and oat flours and guar gum from different vendors*.

	Mesh Size, µm					
	600	425	250	180	<180	
Ingredients						Total (g)
Durum flour	0	0	12.0	41.7	45.3	99
Soy flour	5	35	59	1	0	100
Oat flour	2	22	68	5	2	99

	600	425	250	180	149	<149	
Gum vendors							Total (g)
GG1	0	0	0	0	0	99.5	99.5
GG2	0	0.02	0.6	4.2	4.2	90.6	99.6
GG3	0	0	0.03	0.2	0.7	98.8	99.6

*GG1=Guar gum from vendor 1, GG2- Guar gum from vendor 2 and GG3- Guar gum from vendor 3. n=3.

Chemical Properties of Commercial Guar Gums

Guar gum is primarily the ground endosperm of cluster beans (*Cyamopsis tetragonoloba*), which is an annual legume plant. Protein and ash found in GG samples are considered impurities associated with the seed coat that remained in the GG sample after extraction of endosperm during processing. Difference in the processing conditions of GG among different commercial sources or varietal and geographic differences related to the GG plant could account for variation in ash content in GG from different commercial sources (Cunha et al 2007; Liu et al 2007; Pathak et al 2010).

Protein content was similar for each commercial source of GG and averaged 4.17%. Ash content was greatest with GG2 (0.67%), intermediate with GG3 (0.49%) and least with GG1 (0.34%, $LSD_{0.05}$ = 0.01%). Protein and ash contents were similar to other published results (Cunha et al. 2007). For example, GG samples used by Wang et al (2003) ranged in protein content from 3.2 to 4.0% and ash content from 0.5 to 3.1%.

HPSEC profiles of the three GG samples are shown in Fig. 8 and all GG samples displayed similar elution profiles. There were small differences in terms of elution times. Guar gum 1 eluted earlier than GG2 and GG3. Weight averaged molecular weight (MWT) of commercial guar gum samples were calculated using series of GPC grade dextran standards. Weight averaged molecular weight of 2.84 x 10^6, 1.77 x 10^6 and 1.72 x 10^6 were determined for GG1, GG2 and GG3, respectively.

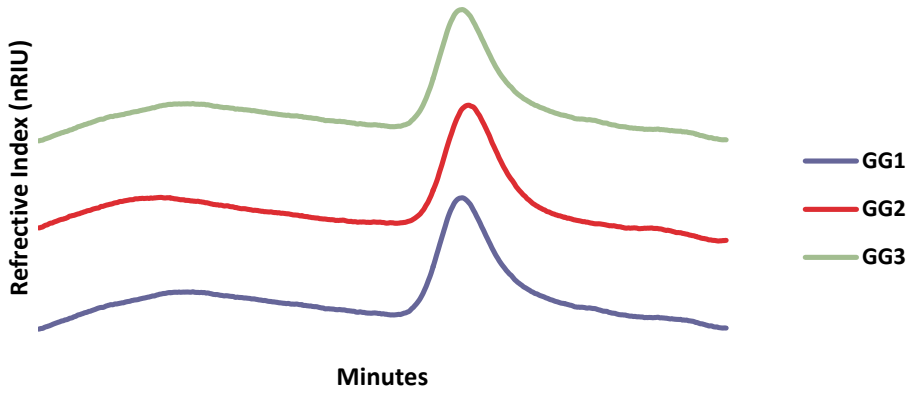


Fig. 8. High performance size exclusion chromatography profiles of guar gum from three vendors. GG1=Guar gum from vendor 1, GG2- Guar gum from vendor 2 and GG3- Guar gum from vendor 3.

Monosaccharide composition of the three GG samples after hydrolysis included glucose, arabinose, galactose, mannose, and xylose. The concentration of the hydrolyzed sugars differed among the commercial sources (Table 9). As expected, mannose and galactose were the predominant sugar moieties since GG is comprised of (1,4)-linked *β*-D-mannopyranosyl backbone, linked to single (1,6)- linked α-D galactopyranosyl residues. The Mannose:Galactose ratio of 1.76, 1.63, and 1.73 were determined for GG1, GG2 and GG3, respectively. Thus, Mannose:Galactose ratio was lower for GG2 than for GG1 or GG3. The Mannose:Galactose

ratios were typical for GG, which ranges from 1.5 to 2.0 (Anderson 1949; Whistler and Hymowitz, 1979). Glucose and arabinose are commonly found with GG (Debon and Tester 2001; Ibanez and Ferrero 2003). Cunha et al (2007) reported arabinose and glucose contents of 4.10 and 3.29%, respectively, for a commercial GG. Arabinose and xylose are common cell wall component in plants. The presence of arabinose and xylose in gums has been attributed to impurities from the seed coat (Ibanez and Ferrero 2003).

Table 9. Mean values for monosaccharide composition in wt% for guar gum from different vendors.

Vendor**	Arabinose	Glucose	Xylose	Mannose	Galactose	Mannose:Galactose
GG1	0.23	4.83	Nd*	60.54	34.40	1.76
GG2	1.48	11.16	0.96	53.18	32.75	1.63
GG3	0.62	7.30	Nd	58.35	31.25	1.73

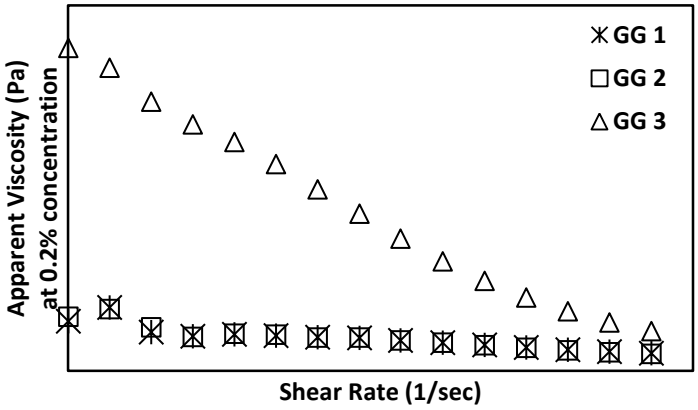
*Nd=Not detected, **GG1- Guar gum from vendor 1, GG2 from vendor 2, and GG3 from vendor 3, n=3.

Viscosity of Commercial Guar Gum Solutions

Viscosity of GG varied both with concentration (0.2, 0.3 and 0.4% wt/v) and with different commercial sources. GG viscosity showed typical shear thinning behavior (Fig. 9). Effect of GG concentration on viscosity displayed unexpected results since behavior of the GG samples followed different trends at each concentration. At lower concentration (0.2%), GG3 had the highest viscosity (approximately 0.16 PaS) compared to GG1 and GG2, which had similar and lower viscosity (approximately 0.03 PaS) (Fig. 9A). Results indicate that GG3 had greater potential to develop high viscosity when used at lower concentration for example 0.2% compared to other sources (GG2 and GG3) of GG. Having the high viscosity at low concentration is an important characteristic because commercially GG is often used in various food applications at relatively lower concentration (0.2%) (Ward 2000). At 0.3%, all three GG

samples differed in their viscosity (Fig. 9B). GG1 had the highest viscosity (approximately 0.17 PaS), followed by GG2 (approximately 0.11 PaS) and GG3 (approximately 0.05 PaS). Ranking of GG samples changed as concentration changed. Comparing 0.2 to 0.3% GG, the viscosity of GG1 and GG2 increased while viscosity of GG3 was less. At 0.4% GG, viscosity results were different again (Fig. 9C). Guar gum 2 attained its highest viscosity (approximately 0.63 PaS), followed by GG3 (approximately 0.50 PaS) and GG1 attained lowest level of viscosity (approximately 0.27 PaS).

Viscosity results can be affected by GG particle size distribution (Table 8), GG concentration and GG molecular size (Fig. 8). Particle size distribution (Table 8) affects the ability of GG to hydrate and to produce subsequent viscous solution. Guar gum 3 viscosity at 0.2 % primarily seems to be a function of its small molecular size compared to that of GG1 and GG2 (Fig. 8). Molecular weight and viscosity results showed an inverse relationship with each other. Viscosity was higher with low than high molecular weight. Small molecular size of GG particles enhanced greater exposure of GG structure, thus providing more surface area available for linking to the surrounding water molecules. Intermediate particle size enabled GG molecules to have sufficient space around them to develop linkages with neighboring water molecules and increased the aqueous viscosity. Similar findings for the effect of GG concentration, molecular size and particle size concentration have been well documented by Wang et al (2003). They reported that hydration rate was dependent on GG concentration. The hydration rate increased with increase in concentration in intermediate GG concentration (range 0.5–1.2% w/v) system of high molecular weight samples. In more concentrated systems (>1.2% w/v) of same sample, an increase in concentration suppressed the hydration process and reduced the hydration rate (Wang et al 2003). Molecular weight had significant effect on the hydration rate of GG. An inverse



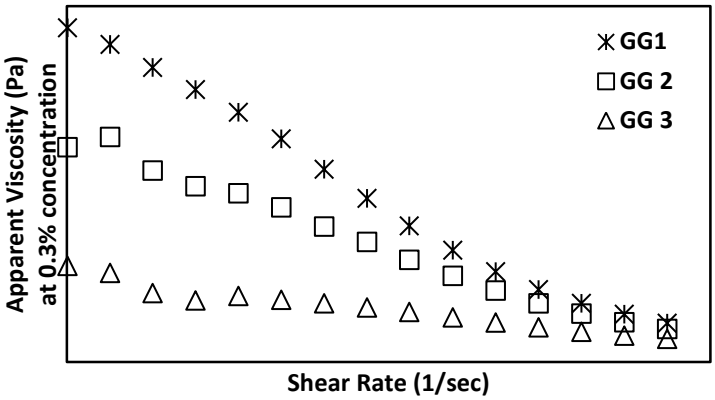


Fig. 9B

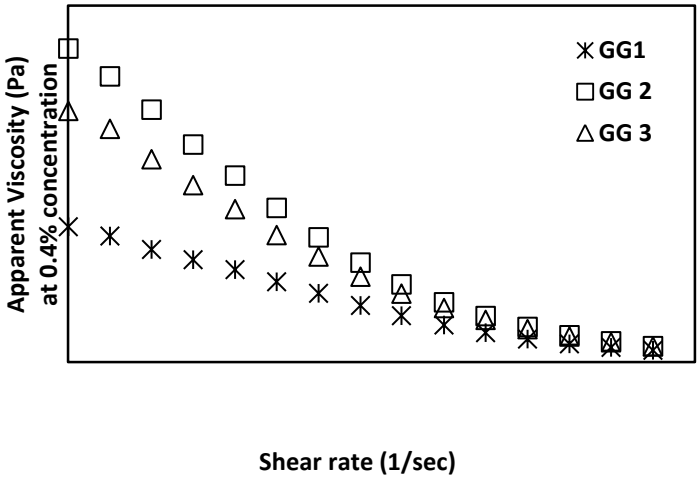


Fig. 9C

Fig. 9. Apparent viscosity (PaS) profiles of guar gums from vendors 1, 2 and 3 at three different concentrations. (A) 0.2% wt/v, (B) 0.3% wt/v, and (C) 0.4% wt/v.

relationship existed between molecular weight and hydration rate of GG samples with molecular weight in range of 0.1–2.8 million. This result was attributed to variation in the molecular weight distribution with respect to particle size, which indicated that particle size (and distribution) and molecular weight were crucial factors in determining net hydration rates (Wang et al 2003).

At 0.3% GG concentration, viscosity data was solely affected by GG molecular size. However, MWT and viscosity showed a direct relationship this time unlike inverse relationship at 0.2 % concentration. Guar gum with higher MWT produced higher viscosity and vice a versa. As the concentration of GG increased to 0.4%, the effect of concentration and particle size seems to be more pronounced. High concentration causes more GG molecules to be present per unit area. Molecules tend to be closer to each other, and which reduced efficiency to bind to the surrounding water molecules. If the particle size of GG is small (for example GG3 and GG1 respectively, Table 8), then particles tend to exert pressure externally on to surface of each other to a greater extent because more surface of GG molecule comes in contact with one another. It prohibits gum molecules to move freely and to develop enough linkages and thus reduces viscosity. While GG2 had largest particles (Table 8), it had intermediate molecular size (Fig. 8) and was still able to produce higher viscosity. Large particle size reduced the contact surface area of particles, increased the space for GG molecules to develop linkages, which in turn increased the viscosity. Guar gum viscosity results are well supported by research conducted by Wang et al (2008). They reported that functional properties of soluble polymers such as GG are reliant on the solution viscosity, which is, in turn, dependent on the rate and extent of dissolution in the aqueous solvent.

Characterization of Durum Flour and Nontraditional Ingredients

Physical and Chemical Properties

Protein content was greatest with soy flour (35.9±0.46%). Durum and oat flours had relatively low protein contents of 13.5±0.12% and 12.4±0.20%, respectively. Lipid content was greatest with soy flour (22.1±0.17%), intermediate with oat flour (7.6±0.31%) and least with durum flour (1.1±0.00%). Dough pH ranged from 6.23±0.04 with oat flour, 6.30±0.06 with durum flour and 6.43±0.03 for soy flour. Swelling volume was greatest with oat flour (10.1±0.21 mL/g), intermediate with durum flour (7.1±0.85 mL/g) and least with soy flour (2.8±0.02 mL/g). Water holding capacity was greatest with soy flour (1.5±0.04 mL/g), intermediate with oat flour (1.4±0.03 mL/g) and least with durum flour (0.9±0.01 mL/g). Water holding capacity seemed to relate with dietary fiber content. Based on the ingredient labels, soy flour had 10.7% dietary fiber, oat flour had 10% dietary fiber, and durum flour had 3.6% dietary fiber.

Bulk density seemed to be inversely related to lipid content and was greatest with durum flour (0.62 g/cm^3), intermediate with oat flour (0.52 g/cm^3) and least with soy flour (0.42 g/cm^3). The particle size distribution is presented in Table 8. Durum flour had the finest particle size with 87% of particles smaller than 250 µm. Soy and oat flours were coarser with 94 and 88 % less than 600 µm but greater than 250 µm, respectively.

Dough Properties

Guar gum generally increased strength of dough made with durum flour. Greatest increase in dough strength occurred with GG1 and GG2 (Fig. 10). Guar gum has been reported to favorably interact with gluten proteins and increase dough stability (Linlaud et al 2009, 2011). Mixograms indicate that compared to durum flour alone, GG dough strength results seem to be related to GG viscosity results (Fig. 9B) where GG1 and GG2 had higher viscosity than GG3,

respectively. Increased dough strength seems to be a function of GG MWT (Fig. 8). Guar gum 1 and GG2, having higher MWT, resulted in stronger dough compared to GG3 with smaller MWT.

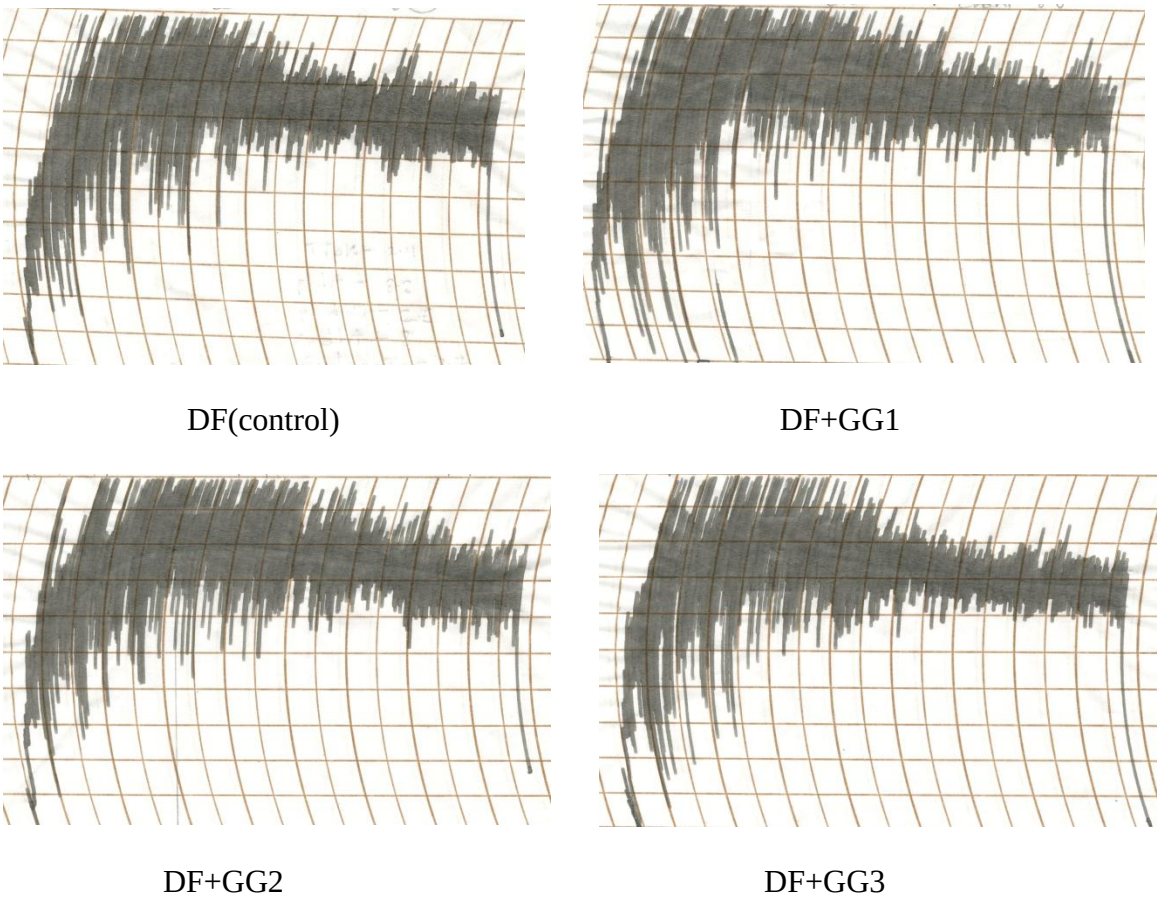


Fig. 10. Mixograms showing strength of dough made with durum flour containing guar gum from different vendors. DF=Durum flour, GG=Guar gum from vendor 1, 2 and 3.

The nontraditional ingredient x GG vendor interaction was not significant for any of the dough quality parameters (Table A6). Nontraditional ingredient main effect was significant for mixogram peak height, end height and end width. Nontraditional ingredients reduced dough strength of durum flour. For example compared to durum flour alone, both soy flour and oat flour reduced peak height and end height (Table 10). Durum flour+soy flour blend had the greatest end width (1.64 BU) compared to durum flour+oat flour (1.15 BU) and durum flour

alone (1.18 BU), which reveals greater stability of dough towards mixing. It could be attributed to high protein content in soy flour (36%).

Table 10. Effect of nontraditional ingredients averaged over guar gum vendor on mean values* for mixogram dough strength parameters of durum flour blends.

Blends	PkHt (BU)	EndHt (BU)	EndWd (mm)
Durum Flour	8.19a	6.99a	1.18b
Durum+Soy Flour	7.32b	6.35b	1.64a
Durum+Oat Flour	7.43b	6.15b	1.15b
LSD**	0.42	0.28	0.14

*Values shown in the table are means for gum sources and those followed by same letter are not significantly different at *P*=0.05. PkHt=Peak height; EndHt= End height; EndWd= End Width; BU=Brabender units.
**Least significant difference.

Guar gum vendor main effect was significant for end width. GG1 had highest mixogram end width (1.46 BU compared to 1.14 BU for GG3 and 1.17 BU for GG2; LSD $_{0.05}$=0.14). A wide end width is an indicator of a strong dough and tolerance to overmixing (Gras et al 2000). Linlaud et al (2009) reported that dough stability was greater with GG than without GG. Wide end width could be attributed to smallest particle size of GG1 (Table 8). Small particle size has offset the effect of the relatively low water holding capacity of GG1. Fine particles of GG1, would provide greater surface area and were able to bind larger amount of water during hydration. Guar gum when present in a blend retained most of the water of hydration and prevented water from interacting with durum flour, reducing the moisture available for gluten/dough development. Dough strength is greatly affected by available moisture; as available water decreases, apparent dough strength increases.

Pasta Processing and Quality

Hydration of Ingredients

Hydration and initial mixing of durum flour alone was done with mixing bowl paddles rotating at 60 rpm for 2 min then at 180 rpm for 2 min, for a total mixing time of 4 min. Mixing of durum flour during the hydration stage of processing resulted in small aggregate particles (3-5 mm dia.). The hydrated flour aggregates did not stick to the sides of the mixing bowl or paddles.

Hydration and mixing of durum flour containing GG required the omission of the slow mixing (60 rpm) step and required fast mixing (180 rpm) for 2 to 3 min. The ingredients appeared uniformly hydrated and felt somewhat dry to touch as compared to durum flour alone. It could be due to small particle size of GG compared to durum flour, soy flour and oat flour. Guar gum hydroxyl groups are in cis-position and it causes hydroxyl groups to reinforce each other in hydrogen bonding reactions. This aids in increasing water binding potential of GG (Fox 1992). Ultimately, the GG out competed the durum flour for moisture so that overall blend texture felt dry to touch.

Durum flour + soy flour blend and durum flour + soy flour + GG blend were hydrated and mixed at 60 rpm for 3 min. Longer mixing times resulted in ingredient blends sticking to the wall of the mixing bowl. Hydrated mass felt dry as compared to durum flour alone.

Treatment containing durum flour + oat flour and its blend with GG were hydrated and mixed at 180 rpm for 4 min. Texture of hydrated mass of blends was similar to that of hydrated durum flour. Hydration did not appear to be uniform. There were random patches of dry and wet particles. Therefore, the amount of water added was not enough to produce uniform hydration. Blends needed more moisture for complete hydration of all particles. Presence of high amount of fiber content in oat flour particles (Doehlert and Moore 1997; Mitra et al 2012) might have

resulted in greater water absorption. Constituents of durum flour were left under-hydrated and overall the blend looked dry.

Extrusion

Nontraditional ingredient x GG interaction and GG main effect were not significant for extrusion pressure, extrusion rate, mechanical energy or specific mechanical energy (Table A7). However, nontraditional ingredient main affect was significant for extrusion pressure, mechanical energy and specific mechanical energy. Hydrated durum flour had highest extrusion pressure, mechanical energy, and specific mechanical energy compared to blends containing oat flour or soy flour. As evident from mixograph results (Table 11), nontraditional ingredients weaken the dough probably by interfering with development of continuous gluten matrix. Compared to durum flour control, extrusion pressure was significantly ($LSD_{0.05}$ = 39.2 psi) reduced 43.6% and 22.7% by oat and soy flours, respectively, mechanical energy was significantly ($LSD_{0.05}$ = 24.1 J/sec) reduced an average of 32.3% by both soy and oat flours; and specific mechanical energy was significantly ($LSD_{0.05}$ = 6.9 J/g) reduced an average of 25.7% by both soy and oat flours (Table 11). Guar gum and nontraditional ingredients did not affect extrusion rate. These results reflect the reduction in strength associated with dough containing soy and oat flour as measured by mixograms (Table 10). Wood (2009) studied texture, processing and organoleptic properties of chickpea-fortified spaghetti. She reported that gluten content/composition appeared to be more important than protein content for pasta firmness, that spaghetti processing and handling characteristics deteriorated as the level of fortification increased and that functional dough properties and spaghetti firmness were generally hindered by increasing amounts of chickpea flour.

Table 11. Effect of nontraditional ingredients averaged over guar gum vendor on mean values* for pasta extrusion parameters of durum flour blends.

Ingredients	EP (Psi)	ME (J/sec)	SME (J/g)
Durum flour	590 a	256 a	74.6 a
Durum flour+Soy flour	481 b	205 b	57.8 b
Durum flour+Oat flour	411 c	182 b	53.1 b
LSD**	39.2	24.1	6.9

*Mean values are shown in the table and those followed by same letter are not significantly different at *P*=0.05.
**Least significant difference, EP-Extrusion pressure, ME-Mechanical energy, SME-Specific mechanical energy.

Guar gum vendor main effect was significant for extrusion rate (g/sec) (Table A8). Extrusion rate was less with GG1 (3.5 g/sec) and GG3 (3.4 g/sec) than with GG2 (3.6 g/sec) ($LSD_{0.05} = 0.16$). These results reflect the effect of variation in the MWT (Fig. 8), viscosity (Fig. 9B) and dough strength (Fig. 10) of GG1, GG2 and GG3. GG1 and GG2 having higher MWT (Fig. 8), higher viscosity (Fig 9B) and stronger dough strength (Fig. 10) resulted in greater extrusion rate than did GG3.

Physical Quality

Freshly extruded spaghetti containing durum flour or durum flour + GG blend was very uniform in appearance and was soft and smooth to the touch. Spaghetti extruded from durum flour + soy flour blend was firm to touch while from durum flour + soy flour + GG was soft but not smooth to touch. Spaghetti extruded from durum flour + oat flour and durum flour + oat flour + GG blend was soft but not smooth to the touch and was quite brittle.

Nontraditional ingredient x GG interaction effect was not significant for any of the color quality parameters (Table A9). Guar gum, averaged over commercial sources, had significant effect on CIE L-value and *b*-value and non-significant affect on *a*-value (data not presented).

Compared to durum flour alone (L-value was 57.9, *b*-value was 35.1), durum flour with GG reduced both L-value (56.6; $LSD_{0.05} = 0.5$) and *b*-value (33.8; $LSD_{0.05} = 0.4$). The difference is so small that it probably has a negligible effect on the overall quality of pasta. Guar gum vendor main effect was significant for CIE *b*-value. Guar gum 3 having most fine particle size (Table 8) had a lowest *b*-value (33.47) compared to 34.03 for GG1 and 34.21 for GG2 ($LSD_{0.05} = 0.41$).

Nontraditional ingredient main effect was significant for CIE L-value, *a*-value and *b*-value. Durum flour and durum flour + soy flour pasta had higher CIE L-values (57.62 and 57.97, respectively) than did durum flour + oat flour pasta (L-value = 54.39; $LSD_{0.05} = 0.51$). Soy flour increased the redness (*a*-value) from 5.09 (durum flour) to 9.62 ($LSD_{0.05} = 0.91$). Durum flour pasta had a high *b*-value 36.22 compared to 34.21 for durum flour + soy flour and 32.95 for durum flour + oat flour ($LSD_{0.05} = 0.53$).

Cooking Quality

Nontraditional ingredient x GG interaction, GG main effect, and GG vendor main effect were not significant for any of the cooking quality parameters (Table A10). Aravind et al 2012 reported that GG at 2.5 % w/w did not affect cooking time, cooked firmness, cooking loss, or cooked weight (water absorption). Brennan and Tudorica (2007) also reported that GG at 2.5 % did not affect cooked firmness of spaghetti.

Nontraditional ingredient main effect was significant for cooked weight, cooking loss and cooked firmness (Table A10). Durum flour and durum flour + oat flour spaghetti had similar cooked weights 31.6% and 32.1%, respectively; both of which were greater than cooked weight for durum flour + soy flour (30.3%; $LSD_{0.05} = 0.59$) (Table 12). Results are similar to research conducted by Yaseen and Shouk (2007) where addition of fiber sources (orange, carrot and potato fiber) increased the weight and volume of the cooked pasta. Cooking loss was greater

from spaghetti containing soy flour (7.2%) or oat flour (7.9%) than from spaghetti made with only durum flour (6.7%; $LSD_{0.05} = 0.27$). Cooked firmness, durum flour and durum flour + soy flour spaghetti had similar and higher cooked firmness (22.4 gcm) than oat flour spaghetti (18.3 gcm; $LSD_{0.05} = 1.56$). High cooked firmness of soy flour spaghetti could be potentially due to its high protein content (36%). Previous studies have shown that increasing the protein content of durum flour spaghetti increases firmness of spaghetti (Nobile et al 2005; Sissons et al 2005). Soy flour does not add any additional gluten to durum flour. Due to exceptionally high protein content in soy flour, there is an over-all increase in the protein content of the blend, which aids in increasing the firmness of spaghetti. In reality, soy flour dilutes the gluten content of durum flour and results in weakening of gluten matrix. Development of weak gluten matrix in blends containing soy flour might have increased leaching of amylose during the cooking process. Increased cooking losses in soy flour spaghetti could also be related to the contrasting differences between soy and gluten proteins in terms of their water solubility, their primary structure and size distributions (Lorimer et al 1991; Wagner and Anon 1990) and lack of interactions between soy and gluten proteins (Ryan et al 2002). Lamacchia et al (2010) reported that soy proteins of defatted soy flour interact with semolina proteins forming larger polymers and provides a disruption of the gluten proteins S–S system and subsequent weakening of gluten matrix.

Table 12**.** Effect of nontraditional ingredients on the cooking quality* of pasta, averaged over guar gum commercial sources.

Blends	Cooked weight (%)	Cooking loss (%)	Cooked Firmness (gcm)
Durum flour	31.6a	6.7c	22.4a
Durum flour+Soy flour	30.3b	7.2a	22.4a
Durum flour+Oat flour	32.1a	7.9b	18.3c
LSD**	0.59	0.27	1.56

*Values shown in the table are means for gum sources and those followed by same letter are not significantly different at *P*=0.05.
**Least significant difference.

Conclusion

Physicochemical characteristics of GG varied among its commercial sources. Irrespective of commercial source hydration and mixing of durum flour containing GG required fast mixing (180 rpm) for shorter time (2-3 min compared to 4 min). Hydrated blends felt dry to the touch as compared to durum flour alone. Guar gum generally increased strength of dough made with durum flour. Greatest increase in dough strength occurred with GG1 and GG2. Mixograms indicate that compared to durum flour alone, GG dough strength results seem to be related to GG viscosity results where GG1 and GG2 had higher viscosity than GG3 respectively. Guar gum affect on dough strength is likely to be a function of GG MWT. GG1 and GG2, having higher MWT, resulted in stronger dough compared to GG3 with smaller molecular size. Guar gum had no significant affect on the extrusion and cooking quality of pasta. Small differences in physicochemical characteristics of GG from different commercial sources had no significant affect on processing or cooking quality of pasta made from durum flour.

Differences in performance of GG from varied sources in dough strength might is significant from a commercial perspective. Extrusion rate is highly dependent on dough strength

and is an important factor in pasta processing plants that affects production. Extrusion rate affects economical balance of commercial pasta company. Variability in GG functionality can therefore affect extrusion rate and plant product output.

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PAPER 3. PHYSICOCHEMICAL CHARACTERISTICS OF COMMERCIAL LOCUST BEAN GUMS AND THEIR EFFECT ON PROCESSING AND COOKING QUALITY OF NONTRADITIONAL PASTA

Abstract

The physicochemical properties of three different commercial sources of locust bean gum (LBG) were determined and its subsequent effect on the processing and cooking quality of pasta containing nontraditional ingredients characterized. Durum flour, soy flour, and oat flour were obtained commercially. Locust bean gum samples were obtained from three different vendors. Durum flour was fortified with nontraditional ingredients (soy flour or oat flour, 10% w/w) and LBG (2% w/w). Hydrated blends were extruded as spaghetti and dried using a high temperature drying cycle (70°C). Bulk density of LBG varied significantly among vendors. For example LBG2 (LBG from vendor 2) and LBG3 (LBG from vendor 3) had similar bulk density (0.65 and 0.64 g/cm^3, respectively) and LBG1 (LBG from vendor 1) had the lowest bulk density (0.51 g/cm^3, LSD 0.05 = 0.03). There were differences in particle size distribution (percentage of fine particles <149 μm, LBG3 = 77.3%, LBG1 = 57.2% and LBG2 = 48.3%), weight average molecular weight (MWT of LBG1, LBG2 and LBG3 were 8.27 x 10^6, 5.16 x 10^6, and 4.48 x 10^6, respectively) and viscosity (at 0.2, 0.3 and 0.4% concentrations) of LBG among vendors. Regardless of vendor, LBG increased dough strength of durum flour. Locust bean gum and its commercial sources had no significant affect on the processing and cooking quality of pasta.

Introduction

Locust bean gum is a galactomannan gum that is extracted from seed of carob tree (*Ceratonia siliqua* L) (Kök 2007; Dakia et al 2008). It consists of a linear chain of (1,4)-linked *β*-D-mannopyranosyl backbone, substituted with (1,6)- linked α-D galactopyranosyl units. Locust bean gum normally has mannose to galactose (Man/Gal) ratio of 3.5:1as compared to 1.5:1 for GG (Daas et al 2000). Depending on the origin of the LBG, the galactose distribution on the mannopyranosyl backbone was found to be random, blockwise, or ordered (Daas et al 2000). The blockwise term refers to the number of non-substituted mannose residues liberated during the enzymatic (endo-Mannanase of *Aspergillus niger*) determination of galactose in galactomannan using high-performance anion-exchange chromatography and pulsed amperometric detection (Daas et al 2000). Distribution of galactose on mannopyranosyl backbone, M/G ratio of LBG is affected by genotype, environment, and age of plant (Barbagallo et al 1997; Shawakfeh and Ereifej 2005). Variation in quality can have great impact on the quality of the final product obtained. Dakia et al (2008) reported mannose and galactose content, solubility, molecular weight and dynamic viscosity differed depending on how the LBG was extracted from the carob seed. Locust bean gum has less solubility and is less effective as a stabilizer than GG due to its relatively low number of galactose branch points (Fox 1992).

Commercial suppliers procure raw material to develop processed gum from different parts of the world. Physicochemical properties of LBG and its effectiveness to perform in a food system could vary depending upon the source (Pollard et al 2008). It is believed that this variation in quality and functionality of gums, due to different sources, might affect final quality of the product in which they are used.

Food gums have been added to improve cooking quality of pasta containing nontraditional ingredients (Parada et al 2010). Soluble gums such as GG, LBG and xanthan gum (XG), have potential to affect the internal structure of pasta by their interaction with protein and starch. Scanning electron micrographs published by Linlaud et al (2009) showed that GG seemed to improve gluten network while LBG seemed to disrupt the gluten network and cause formation of aggregates. Confocal laser scanning microscopy indicated that GG surrounds the starch granules (Aravind et al 2012). Linlaud et al (2011) reported that results using FT-Raman indicated that proteins in dough with gums did not unfold as much and that the conformation of disulfide bonds was different from proteins in dough without hydrocolloids. Effect on protein could increase or decrease dough strength. Based on scanning electron micrographs, Linlaud et al (2009) reported that LBG (1.5% w/w) resulted in a less uniform gluten matrix while dough with GG (1.5%) had more continuous gluten network. These results support their farinograph results where LBG increased water absorption but caused a decreased dough development time, and decreased dough stability; while GG at 1.5% w/w increased water absorption, increased dough development time, and increased dough stability. Inclusion of LBG and GG in pasta system is primarily based on their property to thicken and stabilize food matrix by binding water (Churn 1995) and as dietary fiber source (Brennan and Tudorica 2008; Parada et al 2010).

Food gums can interact with starch, subsequently affecting starch pasting properties. Locust bean gum has been reported to increase the Rapid Visco-Analyzer viscosity of the noodle samples (Yalcin and Basman 2008). There is some evidence that gums can coat starch granules; thus, restrict water entry and can interact with amylose which would affect pasting properties particularly in water rich systems (Alloncle et al 1989). Starch coated with gums is protected from α-amylase digestion (Brennan and Tudorica 2008). Compared to the predicted glycemic

index value for the control fresh pasta (glycemic index = 45), scanning electron microscopy results illustrated that inclusion of LBG yielded pasta with glycemic index values of 37 (Brennan and Tudorica 2008).

Traditional pasta is made from semolina, the ground endosperm of durum wheat. Storage proteins found in semolina are classified as prolamin and are able to form a matrix via disulfide bond formation, which is generally referred to as gluten matrix or network. The gluten matrix embeds starch granules and provides the physical strength of pasta. Analysis of the amino acid composition indicates that semolina storage proteins are low in lysine, methionine, and threonine (Kies and Fox 1970). Semolina is also low in dietary fiber, minerals and vitamins.

Nontraditional ingredients, such as oat flour and soy flour, have been added to semolina in order to improve the nutritional and healthful properties of pasta. Oat flour is rich in dietary fiber, particularly, β-glucan, and its protein is more digestible than is protein from semolina. Soy flour contains high levels of protein. Soy protein is rich in the essential amino acids arginine, leucine, lysine, phenylalanine, and valine (Twombly and Manthey 2006). Soy flour also contains nutraceutical compounds such as isoflavones. The proteins of nontraditional ingredients generally do not have the ability to form a matrix. The nontraditional ingredients dilute the available gluten forming proteins and disrupt the matrix often weakening the dough and reducing cooking quality of pasta (Manthey and Schorno 2002; Manthey et al 2004; Sinha and Manthey 2008; Baiano et al 2011).

Abundant literature exists where they have studied quality and functionality of gums from one source. To our knowledge, there has been limited literature where properties, quality characteristics and functionality of the gums from different sources were studied. Also no literature was found that studied effect of different commercial source of LBG on the processing

properties and cooking quality of pasta containing nontraditional ingredients. Therefore, this study was undertaken with an aim to compare and characterize LBG from different vendors and their subsequent affect on the processing and cooking quality of pasta containing nontraditional ingredients.

Materials and Methods

Materials

Commercial patent durum flour was obtained from the North Dakota Mill and Elevator, Grand Forks, ND. Soy flour and oat flour were obtained commercially from a local grocery store. Locust bean gum was procured from three different vendors (Cargill Texturizing Solutions, Wayzata, MN, USA; Sigma-Aldrich, St. Louis, MO, USA; Tic-Gums, White Marsh, MD, USA). Dextran standards were purchased from Sigma Aldrich Corporation (St. Louis, MO). The gel permeation grade dextran standard molecular weights were as follows: 48,600, 147,000, 273,000, 409,800, 667,800, 1.4 million, and 5-40 million Da.

Flour blends were prepared by fortifying durum flour with nontraditional ingredients (soy flour and oat flour, 10% w/w) and LBG (2% w/w). Uniform blends were prepared by mixing ingredients for 5 min using a cross-flow blender (Patterson Kelly, East Stroudsburg, PA, USA). The 10% level of nontraditional ingredients was selected because previous research has indicated that 10% substitution of nontraditional ingredient generally has little or no effect on pasta quality (Marconi and Carcea 2001; Zhao et al 2005). For gums, the 2% represents the maximum amount that would be used. It is the amount that previous researchers had indicated would have a positive effect on pasta quality (Manthey and Sandhu 2008).

Characterization of Ingredients and Flour Blends

Particle size distributions were determined using a Ro-Tap mechanical shaker (W.S. Tyler, Mentor, OH, USA) with US Standard sieves 30, 40, 60, 80 and 100 (600, 425, 250, 180 and <180 μm, respectively). A 100 g sample was run for 5 min. Each sample was evaluated in triplicate.

Bulk density of individual ingredients was measured using a test weight apparatus (Seedburo Equipment Co., Des Plaines, IL, USA). Material was poured into a standard one quart container with excess material removed using a leveling stick in the manner used to determine test weight of grain. The weight of material per 0.95 L (1 quart) was converted to g/cm^3.

Individual ingredients were analyzed for ash, moisture, and protein contents according to Approved Methods 08-01.01, 44-15.02, and 46-30.01, respectively (AACC International 2010). The conversion factor used to determine protein content was %N x 5.7 for durum flour and %N × 6.25 for soy flour, oat flour, and LBG. Lipid contents were determined using a 16 hr Soxhlet extraction with hexane, according to Method Ba 3–38 (AOCS 1998). Dough pH of durum flour, soy flour and oat flour was determined according to Approved Methods 02-52.01 (AACC International 2010). Blends were analyzed for dough strength as measured by mixograph (National Manufacturing, Lincoln, NE, USA) according to Approved Method 54-40.02 (AACC International 2010).

Swelling Volume

Swelling volume of durum flour ingredients was determined using Approved Method 52-21.01 (AACC International 2010). Durum flour, soy flour and oat flour and blends were weighed (0.25 g) into preweighed centrifuge tubes (15 mL). Distilled water (15 mL) was added to tubes containing sample and were mixed on a vortex mixer for 10 sec. Sample tubes were then placed

in a 70°C water bath for 4 min, mixed on a vortex for 20 sec, placed back in 70°C water bath for 6 min, then transferred to a boiling water bath for 10 min, placed in cold water for 5 min and then centrifuged at 3,500 revolutions per minute (rpm) for 4 min. Supernatant was carefully removed with a transfer pipette and tubes were weighed. Swelling volume was calculated as follows:

$$\text{Swelling volume} = (\text{sediment weight})/(\text{dry sample weight})$$

Approximate Water Holding Capacity

Approximate water holding capacity of durum flour, soy flour and oat flour were determined according to Approved Method 56-30.01 (AACC International 2010). For LBG, method 56-30.01 (AACC International 2010) was used with some modifications as described below. Samples were weighed (0.45 g than 1 g as indicated in the method) on an 'as-is moisture' (i.e., wet basis, wb) into a preweighed 50 mL centrifuge tubes (transparent polycarbonate). A small sample size was selected with an aim to get appropriate results due to the strong hydration capacity of gum. Distilled water was added in small increments and was stirred with glass rod after each addition until sample was thoroughly wetted. Stirring rods were wiped on the sides of the tube. Samples were centrifuged at 2,000 rpm for 1.5 hr and the supernatant removed and discarded. At least three replicates were performed for each sample. The approximate water holding capacity was calculated as:

$$\text{Approximate water holding capacity (mL/g)} = [(\text{tube weight}+\text{sediment weight})-(\text{tube weight} +0.45)]/0.45$$

Water Holding Capacity

Durum flour, soy flour and oat flour and LBG were weighed into each of four tubes after calculating weight of the material according to the following formula

Material weight =15/ approximate water holding capacity +1,

where 15 is the desired total weight of the sample and water. The volume of water added to the first and second tubes were 1.5 and 0.5 mL more, respectively, and the volume of water added to the third and fourth tubes were 1.5 and 0.5 mL less, respectively, than the calculated volume of water (15 - material weight). Contents of the each tube were vigorously mixed with a stirring rod for 2 min and were centrifuged at 2,000 rpm for 1.5 hr. Any two adjoining tubes, one with minimum and one with maximum supernatant, represented the range in which water holding capacity value would occur. Water holding capacity was presented as true midpoint between volumes of these two tubes (e.g. volume of tube 1 and 2) divided by material weight.

Physicochemical Characterization of Locust Bean Gum

Stock solutions (0.5%, w/v) of LBG samples obtained from three different commercial sources were prepared. Weight of the gums was calculated on an 'as-is moisture' (i.e., wet basis, wb). Locust bean gum from varied sources were weighed 1.25 g and were thoroughly dispersed in 250 mL volumetric flask containing 200 mL of doubly distilled water (ddH_2O) followed by addition of Na-azide salt (0.2% of Na-azide in 250 mL ddH_2O). Na-azide salt was added with an aim to minimize the microbial growth. Gums were allowed to hydrate overnight at 4°C. Gum solutions were then continuously stirred at slow speed with a magnetic stirrer for 2 hr at ambient

temperature. Volume was adjusted to 250 mL using ddH_2O and was heated for 30 min at 75°C in a water bath to hydrate gums completely. Gum solutions were centrifuged at 2,000 rpm for 1.5 hr to separate the insoluble particles. Clear supernatant was collected and insoluble particles were oven dried at 105°C for 7 hr. Upon cooling, dried weight was recorded. Then difference in the weight of original gum sample and dried gum residue was determined, which was used to calculate true concentration of the stock solution as follows:

True Concentration = [(original gum wt – dried gum residue wt)/volume of stock solution]*100

Stock solutions were stored at 4°C to minimize bacterial growth.

High Performance Size Exclusion Chromatography (HPSEC)

The initial stock solutions of LBG samples from different sources were diluted 10 times with ddH_2O. Diluted solution was heated to 50°C, and stirred for 1 hr, and filtered warm through 0.45 µm syringe filters (nylon). A 20 µL volume of gum sample was injected into the Agilent HPLC 1200 series high-performance liquid chromatograph (Agilent Technologies, Wilmington, DE). Waters Ultrahydrogel linear column (7.8 mm x 300 mm) was used to separate the polysaccharides. HPLC grade water was used as mobile phase solvent at a flow rate of 0.4 mL/min at 40°C. An Agilent refractive index detector and PC with ChemStation (HP ChemSation for LC Rev. A.04.01) were used for control and integration. Samples were run in triplicate. Weight-averaged molecular weights were calculated using a series of gas permeation chromatography-grade dextrans.

Monosaccharide Composition

A method described by Blakeney et al (1983) was used to determine monosaccharide composition of LBG samples. Method involved simple and rapid preparation of alditol acetates for monosaccharide analysis. The alditol acetate samples were analyzed on a Hewlet Packard 5890 series II Gas Chromatograph (GC) system with a Flame Ionization Detector (FID) (Agilent Technologies, Inc. Santa Clara, CA). Supelco SP-2380 fused silica capillary column (30 m×0.25 mm×0.2 μm) (Supelco Bellefonte, PA) was used to separate monosaccharides. The system parameters were as follows: injector and detector temperatures of 230°C and 250°C, respectively, flow rate of (the mobile phase gas, Helium) 0.8 mL/min, flow pressure 82.7 kPa and oven temperature of 100°C.

Rheological Measurements

The volume (v_1) of the stock solution required to prepare LBG solutions (0.2, 0.3 and 0.4%, w/v) was calculated using formula

$$(m_1v_1=m_2v_2),$$

where m_1 is true concentration of the stock solution, m_2 is the required concentration of the solution and v_2 is the final volume of the solution that has to be made. Viscosities of LBG samples from different commercial sources were determined at three different concentrations (0.2, 0.3 and 0.4% w/v) using a Stresstech controlled stress/strain rheometer (ATS Rheosystems, Bordentown, NJ) with parallel plates. The solutions were pipetted (0.3 mL) between the plates and evenly spread out and the gap was adjusted to 0.5 mm. A constant shear rate (1/s) of 1.006, 1.589, 2.513, 3.981, 6.304, 10, 15.83, 25.13, 39.55, 63.09, 100, 158.5, 251.2, 397.3, and 631 was

used for analysis and the samples were run at 20°C. Samples were run in triplicate. Values obtained were the average of triplicates that were used to determine final viscosity per sample.

Pasta Processing

Blends (1.3 kg) were hydrated to 32% (wb) with warm distilled water (40°C). The wetted ingredients were mixed at high speed in a Hobart mixer (Hobart Corp., Troy, OH, USA) for 4 min and placed in the mixing chamber of the pasta extruder. Mixing during hydration was done in 3 steps. First, water was added to the ingredients as mixing bowl paddles rotated at 60 rpm; second, mixing continued for 90 sec at 60 rpm; then paddle speed was increased and maintained at 180 rpm for 2 min. Total mixing time was 4 min.

The mixtures were extruded under vacuum as spaghetti using a DeMaCo semicommerical laboratory extruder (DEMACO, Melbourne, FL, USA). Extrusion conditions were: extrusion temperature, 45°C; mixing chamber vacuum, 46 cm of Hg; and screw speed, 25 rpm. The extrusion screw had a length to diameter ratio of 8.5:1, a constant root diameter and uniform pitch of the entire length of the screw.

Mechanical energy (ME; J/s), extrusion rate (ER; g/s), and extrusion pressure (EP; psi) were recorded during the extrusion of each sample. Specific mechanical energy (SME; KJ/ kg) was calculated as the ME/ER. The ME required to operate the empty pasta press was subtracted from the ME required to operate the press under load. After extrusion, spaghetti was dried in a laboratory pasta dryer using a high temperature (70°C) drying profile.

Spaghetti Color and Cooking Quality

Color of the spaghetti was determined by measuring CIE L, *a*, and *b* values using a Minolta CR-310 Colorimeter (Minolta Corp., Ramsey, NJ). L-value represents brightness; *a*-

value represents redness when positive and greenness when negative; and *b*-value represents yellowness when positive and blueness when negative.

Spaghetti (10 g) was cooked for 12 min in a glass beaker containing 300 mL boiling water. Cooking was performed using Method 66-50.01 (AACC International, 2010). Cooked samples were drained for 2.5 min and then weighed to measure cooked weight. Cooking loss (weight of total solids) was measured by evaporating cooking water to dryness in a forced-air oven at 110°C. The cooked samples were measured for their firmness using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA). Firmness was measured by the amount of work (g cm) required to shear five cooked strands of spaghetti using a pasta blade probe attached to the texture analyzer.

Experimental Plan and Statistical Analysis

The experimental design was a randomized complete block with factorial arrangement for fixed effects of nontraditional ingredients and LBG vendors. Three replicates were performed on each treatment. Each replicate was extruded on a separate day. Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC, Software). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Results and Discussion

Characterization of Commercial Locust Bean Gums

Physical Properties of Commercial Locust Bean Gums

Bulk density of LBG samples significantly ($LSD_{0.05} = 0.03$) differed among vendors. LBG2 and LBG3 had similar bulk density (0.65 and 0.64 g/cm^3, respectively) while LBG1 had the lowest bulk density (0.51 g/cm^3). Bulk density is a measure of packing of particles together.

High or low bulk density could be attributed to the shape of the gum particles. However, bulk density did not appear to relate to particle size distribution. Particle size distribution varied among different vendors of LBG. Locust bean gum 3 had the highest percentage of fine particles <149 μm (77.3%) followed by LBG1 (57.2%) and LBG2 (48.3%) (Table 13). Particle size distributions are similar to that reported in the literature (Boulos et al 2000). Water holding capacity (9.46 mL/g) was similar for LBG from all three vendors. There does not seem to be a relationship among bulk density, particle size distribution and water holding capacity.

Table 13. Mean values for particle size distribution (%) of locust bean gum from different vendors*.

	Mesh Size, μm						
	600	425	250	180	149	<149	
Gum vendors							Total (g)
LBG1	0.0	0.0	0.1	23.4	18.6	57.2	99.2
LBG2	0.0	0.0	1.6	43.9	5.2	48.3	99.0
LBG3	0.0	0.0	0.4	2.6	18.6	77.3	99.0

*LBG1=Locust bean gum from vendor 1, LBG2=Locust bean gum from vendor 2 and LBG3=Locust bean gum from vendor 3. n=3.

Chemical Properties of Commercial Locust Bean Gums

Presence of protein and ash were detected in LBG obtained from different commercial sources. Significant differences ($LSD_{0.05} = 0.4$) in protein content for LBG1, LBG2 and LBG3 (6.3, 6.6 and 4.4%, respectively) were observed. Whereas the ash contents of 0.97, 0.97 and 0.93% for LBG1, 2 and 3, respectively, were not significant ($LSD_{0.05} = 0.04$). These results are similar to those reported by Kök et al 1999 and Dakia et al 2008. Protein and ash content are not part of LBG structure and could be attributed to the presence of structural proteins and enzymes in the endosperm and to the incomplete separation of germ from endosperm during the manufacturing process. Germ is rich in protein and contains minerals, which could be a potential source of protein and ash in the final LBG product (Dakia et al 2008).

HPSEC profiles of the three LBG samples were similar and are shown in Fig. 11. There were differences in the weight averaged MWT of LBG from different vendors. MWT of LBG1, 2 and 3 were 8.27 x 10^6, 5.16 x 10^6 and 4.48 x 10^6, respectively. These results are similar to those reported by Rizzo et al (2004), who reported molecular weights of 2.6 x 10^6 to 3.0 x 10^6. Pollard et al (2008) reported only small differences in molecular weight among commercial samples and that variation consisted primarily of minor differences in the chromatographic peak height and width.

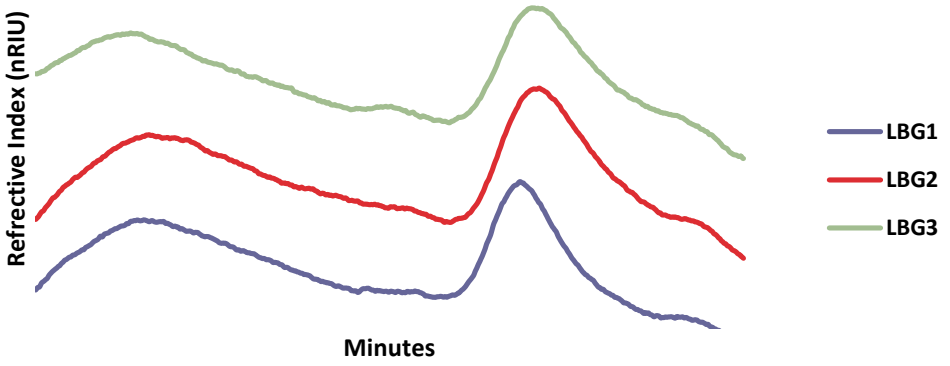

Fig. 11. High performance size exclusion chromatography profiles of locust bean gum from three different vendors. LBG1- locust bean gum from vendor 1, LBG2- locust bean gum from vendor 2 and LBG3- locust bean gum from vendor 3.

GC analysis of monosaccharide composition and content (%) of LBG detected galactose, mannose, glucose, arabinose and xylose in LBG from different vendors (Table 14). Structurally LBG is a linear chain of 1,4 β-D-mannopyranosyl units with 1,6 α-D-galactopyranosyl residues irregularly spaced on the chain. Depending on the origin of the LBG, the galactose distribution on the mannopyranosyl backbone was found to be random, blockwise, or ordered (Daas et al 2000). Thus, LBG contains only mannose and galactose sugar units and mannose is the

predominant sugar followed by galactose. The mannose:galactose ratio (M:G) greatly affects LBG functionality. Locust bean gum from different vendors differed in their M:G. M:G ratio was greatest with LBG2 (3.73:1), intermediate with LBG3 (3.52:1), and lowest with LBG1 (3.44:1). M:G ratio of LBG is affected by genotype, environment, and age of plant (Barbagallo et al 1997; Shawakfeh and Ereifej 2005). The amount of mannose and galactose and the subsequent M:G ratio were similar to that published by Kök et al. (1999), Rizzo et al (2004) and Dakia et al (2008).

Table 14. Mean values for monosaccharide composition in wt% for locust bean gums from different vendors*.

Monosaccharide	LBG1*	LBG2*	LBG3*
Mannose	60.0	75.0	73.1
Galactose	17.5	20.1	20.7
Glucose	22.3	4.9	6.2
Xylose	0.1	Nd**	Nd**
Arabinose	0.2	Nd**	Nd**
M:G***	3.44	3.73	3.52

*LBG1- locust bean gum from vendor 1, LBG2- locust bean gum from vendor 2 and LBG3- locust bean gum from vendor 3, **Nd=Not detectable; ***M:G=Mannose to Galactose ratio; n=3.

Presence of sugars except Man and Gal are considered as contaminants. Glucose, arabinose, and xylose were detected in LBG1 while only glucose was detected in LBG2 and LBG3. Kök et al (1999), Rizzo et al (2004), and Dakia et al (2008) also detected xylose, glucose, and arabinose in LBG. The amount of these sugars detected varies greatly in the literature. The glucose (22%) detected in LBG1 is rather high. Rizzo et al (2004) reported a sample with 7.5% glucose and a total of 14.8% for fructose, glucose, and sucrose. Sucrose and fructose can be converted to glucose affected by acid hydrolysis. Rizzo et al (2004) and Kök (2007) reported wide fluxuation in content of sugars other than galactose and mannose.

Arabinose is a common constituent of plant polysaccharides and is present in the cell wall. Another natural sugar, xylose, is commonly found in woody materials, e.g, straw, shells and hulls. Parts of cell wall and hull of carob seed could be the potential source of arabinose and xylose in LBG gum (Brennan et al 1996). Kok (2007) proposed the possible existence of arabinogalactan in LBG.

Viscosity of Commercial Locust Bean Gum Solutions

Viscosity of LBG varied among different concentrations and vendors (Fig. 12A, B and C). Locust bean gum1 viscosity varied with concentration. At 0.2%, LBG1 had the lowest viscosity, while at 0.3 and 0.4 % it had the highest viscosity. Locust bean gum1 viscosity results appear to be a function of its mean molecular weight (Fig. 11). High molecular size particles of LBG1 would have less surface area and less galactose branch points available that could interact with neighboring molecules. Cheng et al (2002) reported that aggregation is an intrinsic property of native galactomannan. High molecular weight LBG has more stabilized coil structure with stronger intrinsic associations and less mannose and galactose branch points available for intermolecular interaction (Dakia et al 2008). At 0.2%, LBG1 would have fewer molecules present per unit area. Gum molecules would be far spaced so fewer intermolecular interactions would take place. This would account for reduction in viscosity of LBG1 at 0.2%. At the higher concentrations (0.3 and 0.4%), LBG1 would have a greater number of molecules per unit area. Gum molecules being larger in size, would be much closer to each other with enhanced intermolecular interactions and would result in increased viscosity.

Viscosity results for LBG2 and LBG3 were quite consistent over different concentrations (0.2, 0.3 and 0.4%, Fig. 12A, B and C) of LBG. LBG3 always had higher viscosity than LBG2. Both LBG3 and LBG2 had smaller molecular weight than LBG1 and it was smallest for LBG3

compared to LBG2 (Fig. 11). The small molecular weight of LBG3 would account for its viscosity always being greater at the three different concentrations (0.2, 0.3 and 0.4%) than did LBG2, which had comparatively greater molecular weight. Dakia et al (2008) reported that LBG with lower molecular weight dissolves easily at lower temperatures while solubility of higher molecular weight molecules increases with increase in temperature. Compared to LBG with high molecular weight, LBG with small molecular weight would have greater solubility, more intermolecular interactions, and greater viscosity.

Viscosity results for LBG at higher concentrations (0.3 and 0.4%) (Fig. 12B and C) conveyed better information regarding the trend in viscosity of LBG from diverse vendors. LBG showed typical shear thinning (or pseudoplastic) behavior at three different concentrations. Similar findings for decrease in viscosity of LBG, with consistent increase in shear rate has been well documented by Dakia et al (2008) and Mao and Chen (2006).

Characterization of Durum Flour and Nontraditional Ingredients

Physical and Chemical Properties

Soy flour had the highest protein content (35.9±0.46%). Compared to soy flour, durum flour and oat flour had relatively low protein contents of (13.5±0.12%) and (12.4 ±0.20%), respectively. Lipid content was greatest with soy flour (22.1±0.17%), intermediate with oat flour (7.6±0.31%), and lowest with durum flour (1.1±0.00%). Dough pH ranged from 6.23±0.04 with oat flour, 6.30±0.06 with durum flour and 6.43±0.03 for soy flour. Swelling volume was greatest with oat flour (10.1±0.21 mL/g), intermediate with durum flour (7.1±0.85 mL/g) and lowest with soy flour (2.8±0.02 mL/g). Water holding capacity was greatest with soy flour (1.5±0.04 mL/g), intermediate with oat flour (1.4±0.03 mL/g) and lowest with durum flour (0.9±0.01 mL/g). Water holding capacity probably was related to dietary fiber content. Based on the ingredient

labels, soy flour had 10.7% dietary fiber, oat flour had 10% dietary fiber, and durum flour had 3.6% dietary fiber.

Table 15. Mean values for particle size distribution (%) of durum flour, soy flour and oat flour.

	Mesh Size, µm					
	600	425	250	180	<180	
Ingredients↓						Total (g)
Durum flour	0	0	12	42	45	99
Soy flour	5	35	59	1	0	100
Oat flour	2	22	68	5	2	99

n=3.

Dough Properties

Locust bean gum increased dough strength of durum flour, regardless of vendor (Fig. 13). Dough strength as reflected by bandwidth of mixogram was greatest with LBG2. LBG2 maintained greater bandwidth throughout the mixogram than did LBG1 or LBG3. Time-to-peak was longer with LGB2 (2.7 min) than with LBG1 (2.2 min) or LBG3 (2.1 min). Time-to-peak generally reflects the time required to fully hydrate gluten proteins found in wheat flour and to fully develop the dough. Here, longer time-to-peak could also reflect larger particle size of LBG2 than LBG1 and LBG3 (Table 15). Larger particles would hydrate slower than would small particles.

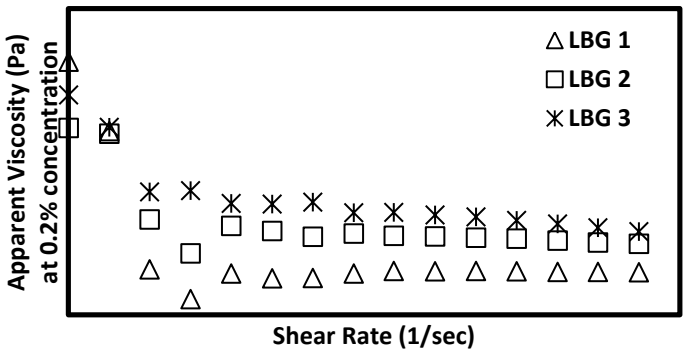

Fig. 12A

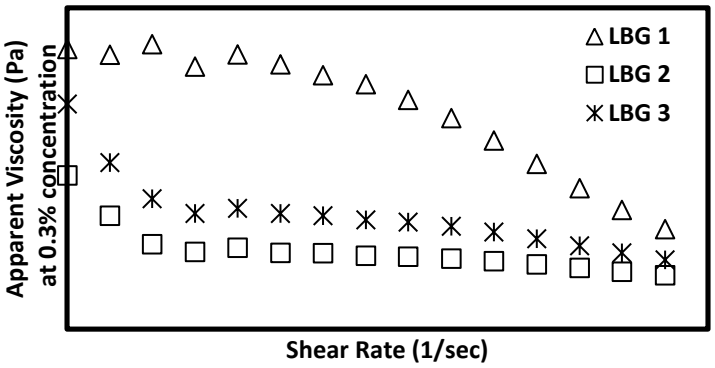

Fig. 12B

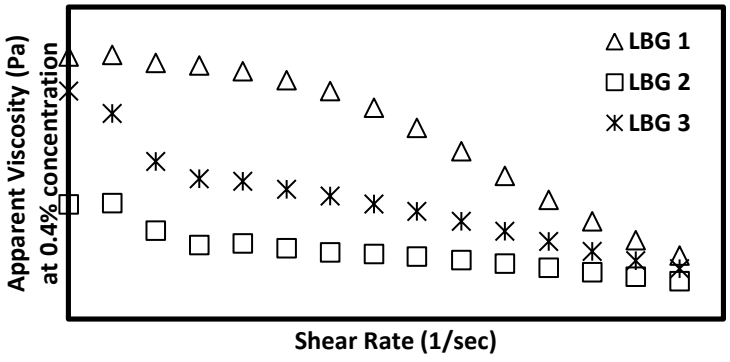

Fig. 12C

Fig. 12. Apparent viscosity (PaS) profiles of locust bean gums from vendors 1, 2 and 3 at three different concentrations. (A) 0.2% wt/v, (B) 0.3% wt/v, and (C) 0.4% wt/v.

The nontraditional ingredient by LBG vendor interaction was not significant for any of the mixogram parameters (Table A11). Nontraditional ingredient main effect was significant for mixogram peak height, end height and end width. Both soy flour and oat flour reduced dough strength of durum flour. Peak height of the mixogram curve was lowest with durum flour+soy flour (7.54 BU), intermediate with durum flour +oat flour (7.79 BU) and greatest with durum flour alone (8.54 BU; $LSD_{0.05}$= 0.18). Height of mixogram curve at 8 min was greater with durum flour (7.56 BU) than with durum flour+soy flour (7.06 BU) or durum flour+oat flour (6.72 BU; $LSD_{0.05}$ = 0.36). Mixogram end width was greatest with durum flour+soy flour (2.08 BU) and was lower and similar with durum flour+oat flour (1.60 BU) and durum flour alone (1.61 BU; $LSD_{0.05}$= 0.26). Results are similar to mixogram results for the main effect of nontraditional ingredients when GG and/or XG were studied for their affect on nontraditional pasta quality (see Paper 2 and 4, Sandhu 2012).

LBG vendor main effect was significant for the end width of the mixogram curve (Table A11). End width was greater with LBG2 (1.98 BU) than with LBG1 (1.66 BU) or LBG3 (1.67 BU; $LSD_{0.05}$= 0.26). Results reflect stronger dough developed by LBG2, which had greater stability to mixing for example durum flour + LBG2 mixogram (Fig. 13).

Pasta Processing and Quality

Hydration of Ingredients

Durum flour was hydrated (32% wb) and mixed at 60 rpm for 2 min and then at 180 rpm for 2 min, which resulted in small aggregate particles (3 to 5 mm dia). The hydrated flour aggregates did not stick to the sides of the mixing bowl or mixing paddles.

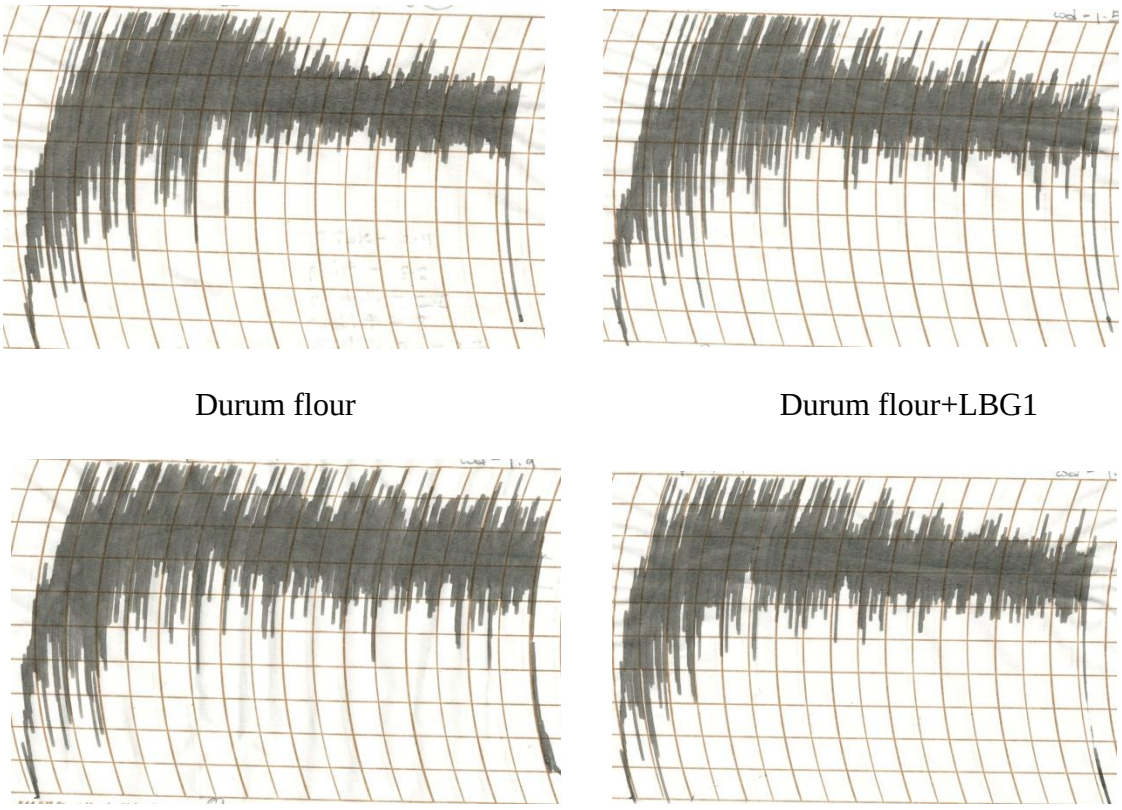

Fig. 13. The effects of locust bean gum commercial sources on durum flour dough strength as measured by mixograph.

Durum flour + LBG blend was hydrated and mixed at 60 rpm for 2-3 min. Controlled mixing time avoided formation of large aggregates. If mixed at 180 rpm for 4 min, aggregates tended to adhere to the sides of the mixing bowl. Hydrated durum flour + LGB appeared and felt wetter than did hydrated durum flour.

Texture of hydrated blend containing durum flour + soy flour + LBG and durum flour + oat flour + LBG were hydrated and mixed at 60 rpm for 3 min without formation of large aggregates. If mixed longer than 3 min or at 180 rpm, wet particles adhered to the sides of the bowl and formed large aggregates. The texture of hydrated durum flour + soy flour + LBG

appeared and felt slightly wetter than did the hydrated durum flour. Texture of hydrated durum flour + oat flour + LBG appeared and felt damp similar to that of hydrate durum flour. Soy flour contained 22% lipid and 10.7% dietary fiber. The lipid portion would not hydrate while the dietary fiber portion would hydrate and bind water. Similarly, oat flour contained 7.6% lipid and 10% dietary fiber. For soy flour, the dietary fiber content, hydrophilic, probably did not offset the effect of lipid content on water binding and resulted in apparent over-hydration, while for oat flour the dietary fiber content probably did offset the effect of lipid content on water binding and resulted in hydration similar to that of durum flour.

Extrusion

Nontraditional ingredient x LBG interaction was not significant for any of the extrusion quality parameters (Table A12). LBG vendor main affect was not significant for any of the extrusion quality parameters (Table A13).

Nontraditional ingredient main effect was significant for extrusion pressure, mechanical energy, and specific mechanical energy (Table A13). Both soy flour and oat flour reduced the extrusion pressure, mechanical energy and specific mechanical energy and these parameters were reduced most by oat flour (Table 16). Compared to durum flour, extrusion pressure was reduced 17.5% and 28.3%; mechanical energy was reduced 16.6% and 25.4%; and specific mechanical energy was reduced 14.9% and 25.6% by soy flour and oat flour, respectively. Results reflect mixograph results where nontraditional ingredients weakened the dough probably by interfering with development of continuous gluten matrix. These results are also similar to the effect of soy flour and oat flour in nontraditional pasta fortified with GG (see Paper 2, Sandhu et al 2012). Wood (2009) studied the texture, processing and organoleptic properties of chickpea-fortified spaghetti. In this study, researchers reported that gluten content/composition appeared to be more

important than protein content for pasta firmness. Spaghetti processing and handling characteristics deteriorated as the level of fortification increased and functional dough properties and spaghetti firmness were generally hindered by increasing amounts of chickpea flour.

Physical Quality

Fresh spaghetti extruded with durum flour alone or with durum flour + LBG was very uniform in appearance and felt soft and smooth to the touch. Spaghetti extruded from durum + soy flour blend was firm to the touch while the durum flour + soy flour + LBG blend was soft to touch and had rough texture. Spaghetti extruded from durum flour + oat flour blend was soft to touch, rough in texture and was quite fragile. Spaghetti extruded from durum flour + oat flour +LBG blend was soft to the touch but rough in texture. Particles of soy flour and oat flour did

Table 16. Effect of nontraditional ingredients averaged over locust bean gum vendor on mean values* for pasta extrusion parameters.

Ingredients	EP (Psi)	ME (J/sec)	SME (J/g)
Durum Flour	593a	251a	74a
Durum flour +Soy flour	490b	209b	63b
Durum flour+Oat flour	425c	187c	55c
LSD**	24	15	4

*Mean values are shown in the table and those followed by same letter are not significantly different at *P*=0.05.
**Least significant difference, EP-Extrusion pressure, ME-Mechanical energy, SME-Specific mechanical energy.

not change much during the kneading and extrusion process. Roughness of spaghetti containing soy flour or oat flour is a reflection of their particle size. Scanning electron micrograms published by Manthey and Schorno (2002) clearly showed intact bran particles embedded in dry wholewheat spaghetti affected appearance that suggested an increased roughness.

Nontraditional ingredient x LBG interaction was not significant for any of the color quality parameters of dry spaghetti. Locust bean gum, averaged over commercial sources, had a significant effect on CIE L-value and *b*-value. Compared to spaghetti made with durum flour (L-value-57.88, *b*-value-35.08), spaghetti made with durum flour + LBG had reduced L-value (57.14; $LSD_{0.05} = 0.47$) and *b*-value (34.31; $LSD_{0.05} = 0.36$). The difference between L-values and between *b*-values were statistically significant but were of no practical importance to the overall quality of pasta.

Locust bean gum vendor main effect was significant for both CIE L-value and *b*-value of dry spaghetti (Table A14). Locust bean gum 2, had a lower L-value (56.32) and b-value (33.55) compared to L-value (57.67) and *b*-value (34.82) of LBG1 and L-value (57.45; $LSD_{0.05} = 0.43$) and *b*-value (34.57; $LSD_{0.05} = 0.53$) of LBG3. Low brightness (L-value) and yellowness (b value) associated with LBG2 and higher L and *b*-values of LBG1 and LBG3 could be related to their particle size. LBG2 had larger particle size while LBG1 and LBG3 had smaller particle size (Table 15). Brightness and yellowness appeared to be affected by ability of LBG to blend with durum flour particles and its hydration properties. Locust bean gum 1 and LBG3 with fine particle sizes would have blended and hydrated uniformly in durum flour. On the other hand, LBG2 with larger particle size might not have blended well in durum flour, resulted in uneven hydration and affected the yellow appearance of spaghetti. This might explain why LBG1 and LBG3 had more brightness and yellowness in pasta compared to LBG2.

Nontraditional ingredient main effect was significant for CIE L-value, *a*-value, and *b*-value of dry spaghetti (Table A14). L-value was greatest for spaghetti made with durum flour (58.78), intermediate with durum flour + soy flour (57.95) and lowest with durum flour + oat flour (54.70; $LSD_{0.05} = 0.43$). Spaghetti made with durum flour + soy flour had highest *a*-value

(9.38) compared to durum flour + oat flour (5.57) and durum flour control (4.84; $LSD_{0.05} = 0.42$). The *b*-value was highest for spaghetti made with durum flour (36.49), intermediate with durum flour + soy flour (33.71) and lowest with durum flour + oat flour (32.73) ($LSD_{0.05} = 0.53$). Results indicate that compared to durum flour control, nontraditional ingredients reduced both L-value and *b*-value and had a negative impact on the color of pasta. Many nontraditional ingredients such as soy flour and soy protein isolates (Brewer et al 1992; Twombly and Manthey 2006); chickpea (Wood 2009); buckwheat bran (Manthey et al 2004); wheat bran (Manthey and Schorno 2002); flaxseed flour (Manthey and Sandhu 2008); oat flour (Mitra et al 2012); legume flour (Zhao et al 2005) have been reported to reduce color and overall appearance of pasta products.

Cooking Quality

Nontraditional ingredient x LBG interaction and LBG vendor main effect were not significant for any of the cooking quality parameters (Table A15). Nontraditional ingredient main effect was significant for cooked weight, cooking loss and cooked firmness (Table A15). When averaged over vendors (Table A16), spaghetti made with durum flour and durum flour + oat flour had higher cooked weights (32.0% and 32.5%, respectively) than spaghetti made with durum flour + soy flour spaghetti (30.1 %; $LSD_{0.05} = 0.51$). Cooking loss was greatest with durum flour + soy flour (7.8%), intermediate with durum flour + oat flour (7.2%) and lowest with durum flour (6.7%; $LSD_{0.05} = 0.37$). Cooked firmness was greatest with spaghetti made with durum flour (22.5 gcm) and durum flour + soy flour (21.2 gcm) and lowest with durum flour + oat flour (18.3 gcm; $LSD_{0.05} = 0.95$).

Lower cooked weight in durum flour + soy flour blends could reflect the high lipid content in soy flour (22.1%) compared to lipid contents of oat flour (7.6%) and durum flour

(1.1%). Additionally, soy flour also had the lowest swelling volume. Low swelling volume might restrict the amount of water or rate of water absorbed during cooking. Zhao et al (2005) reported that legume flours generally decreased cooked weight of spaghetti.

Increased cooking losses in soy flour spaghetti could also be related to the contrasting differences between soy and gluten proteins in terms of their water solubility, their primary structure and size distributions (Lorimer et al 1991, Wagner and Anon, 1990) and lack of interactions between soy and gluten proteins (Ryan et al 2002). Lamacchia et al (2010) reported that soy proteins of defatted soy flour interact with semolina proteins forming larger polymers and provides a disruption of the gluten proteins S–S system and subsequent weakening of gluten matrix.

High cooked firmness of soy flour spaghetti could be related to its exceptionally high protein content (36%) compared to relatively lower protein contents of durum flour (13.5%) and oat flour (12.4%). A similar finding for the affect of soy flour on the cooking quality of pasta by Nasehi et al (2009) documented that addition of full fat soy flour to hard wheat flour decreased ($P \leq 0.05$) the cooking time, cooked weight and increased the cooking losses of spaghetti. Zhao et al (2005) reported that legume flours, with protein contents of 19.5 to 22.6%, increased cooked firmness of spaghetti. High swelling has been associated with reduced cooked firmness due to the increased moisture uptake by pasta (Brennan and Tudorica 2007). Swelling volume was greatest with oat flour (10.1±0.21 mL/g), intermediate with durum flour (7.1±0.85 mL/g) and least with soy flour (2.8±0.02 mL/g). Therefore, confirming the relationship between cooked firmness and swelling volume. Low cooked firmness with oat flour was also reported by Mitra et al (2012).

Conclusion

Locust bean gum characteristics significantly varied among samples from different vendors. There were measurable differences in particle size distribution, molecular size and viscosity of LBG. Viscosity of LBG varied among different concentrations and vendors. At lower concentration (0.2%), LBG1 had the lowest viscosity and at higher concentrations (both 0.3% and 0.4%) it had the highest viscosity. Locust bean gum 2 and LBG3 had consistent viscosity over different concentrations (0.2, 0.3 and 0.4%, Fig 12A, B and C) where LBG3 always developed higher viscosity than LBG2. Regardless of commercial source, LBG increased dough strength of durum flour where LBG 2 promoted dough strength the most. Irrespective of commercial source, hydration and mixing of durum flour containing LBG required slower mixing (60 rpm) for shorter time (2-3 min). Hydrated blend had wet texture compared to durum flour alone. Varied particle size of LBG from diverse vendors affected CIE L and b-values of spaghetti. Locust bean gum and its vendor sources had non-significant affect on the processing and cooking quality of pasta.

Irrespective of the commercial source, LBG enhanced the dough strength, but differed in magnitude only. Locust bean gum did not appear to affect the processing and cooking quality of pasta. Most often scientists are concerned with the effect of gum only, it does not really matter if magnitude of gum affect is different. These results demonstrate that from scientific research perspective, probably vendor source of LBG does not matter.

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PAPER 4. PHYSICOCHEMICAL PROPERTIES OF COMMERCIAL XANTHAN GUMS AND THEIR EFFECT ON PROCESSING AND COOKING QUALITY OF NONTRADITIONAL PASTA

Abstract

The physico-chemical properties of three different commercial sources of xanthan gum (XG) were determined and its subsequent effect on the processing and cooking quality of pasta containing nontraditional ingredients characterized. Durum flour was fortified with nontraditional ingredients (soy flour or oat flour, 10% w/w) and XG (2% w/w). Hydrated ingredients were extruded as spaghetti and dried using a high temperature (70°C) drying cycle. Protein content, ash content, bulk density, water holding capacity, and total glucose content significantly varied among XG samples from different vendors. Xanthan gum increased dough strength of durum flour and the extent of strengthening varied with vendor of XG. For example, time-to-peak ranged from 2.75 to 4.25 min; peak width from 2.5 to 3.75 BU; and end width from 2 to 3 BU depending on the vendor of XG. Processing properties differed depending on commercial source. Samples containing XG from commercial source that had the finest particle size required the lowest mechanical energy (range 253-270 J/sec) and had the greatest extrusion rate (range 3.38-3.65 g/sec), both of which resulted in the lowest specific mechanical energy (range 69-79 J/g) required to extrude spaghetti samples. Xanthan gum did not affect cooking loss but did significantly increase the cooked weight and cooked firmness. The three samples of XG increased cooked firmness similarly. Xanthan gum with the lowest nitrogen content and highest ash content resulted in pasta with the lowest cooked weight.

Introduction

Xanthan gum, an extra cellular high molecular weight heteropolysaccharide, is widely used in processed foods. Xanthan gum is produced by various types of bacteria belonging to *Xanthomonas* spp. such as *X. campestris, X. phaseoli, X. arboricola* and *X. malvacearum* (Leela and Sharma 2000). Commercially, XG is most often derived from a gram-negative bacterium (*Xanthomonas campestris)* by an aerobic fermentation process based on its high yield and high quality product suitable for many applications (El-Enhasy et al 2011). The production process is highly influenced by the type and concentration of the different carbon and nitrogen sources as well as other medium components (Umashankar et al 1996), temperature, pH, aeration and agitation (Shu and Yang 1990, 1991; Garcia-Ochoa et al 2000a; Letisse et al 2002; Borges et al 2008, 2009). Consequently, fermentation conditions affect the quality of XG (Flores-Candia and Deckwer 1999 a,b). The molecular weight values reported in the literature are very diverse. Xanthan gum can vary in pyruvate acid content, trisaccharide side chain, and molecular weight (Born et al 2002; Song et al 2006).

Xanthan gum is most often produced in batch system. Xanthan gum developed at different or same commercial location can show variation in quality due to difference in the strain of microorganism used for XG production (Shu et al 1991; Peters et al 1992; Leela and Sharma 2000; Mohan and Babitha 2010) and due to difference in the processing conditions of processing units (Flores-Candia and Deckwer 1999a, b; Garcia-Ochoa et al 2000b). Thacker et al (2010) reported significant differences in viscosity parameters among different grades and among different lots of a particular grade of XG manufactured at different times.

Traditional pasta is made from semolina, the ground endosperm of durum wheat. Prolamin proteins found in semolina is able to form a matrix, which is generally referred to as

gluten matrix or network. The gluten matrix embeds starch granules and provides the physical strength of pasta. Semolina is low in minerals and vitamins and the amino acid composition of protein is low in lysine, methionine and threonine (Kies and Fox 1970). Nontraditional ingredients, such as oat flour and soy flour, are often added to semolina in order to improve the nutritional and healthful properties of pasta. Oat flour is rich in dietary fiber, particularly β-glucan, and its protein is more digestible than is protein from semolina. Soy protein is rich in the essential amino acids arginine, leucine, lysine, phenylalanine, and valine (Twombly and Manthey 2006). Soy flour also contains nutraceutical compounds such as isoflavones. The proteins of nontraditional ingredients generally do not have the ability to form a matrix. The nontraditional ingredients dilute the available gluten forming proteins and disrupt the matrix often weakening the dough and reducing cooking quality of pasta.

Food gums, such as XG, have been evaluated for their ability to improve the physical and cooking quality of specialty pastas such as fresh, refrigerated, frozen, and canned, along with pasta containing nontraditional ingredients (Manthey and Sandhu 2008, 2009). Brennan and Tudorica (2007) reported that fresh pasta quality was affected by enrichment of food gums and that the magnitude of the effect was dependent on the type, solubility, and concentration of gum used. Xanthan gum has been shown to improve cooked firmness and cooked weight of pasta and noodle products. Generally, non-starch polysaccharide addition increased the cooking losses; diluted durum protein and starch content of pasta and affected the stickiness, adhesiveness and elasticity of pasta.

While there is an abundance of literature examining the quality and functionality of XG from a single commercial source in food systems, published research comparing the effectiveness of XG from different commercial sources is quite limited. A question has arisen

concerning the possible differences in effectiveness of XG obtained from different commercial sources. Also no literature has been published where they have studied the effect of commercial source of gums on processing properties and cooking quality of pasta containing nontraditional ingredients. Therefore, this study was undertaken with an aim to compare and characterize XG as obtained from different commercial sources and to detect its effects on the processing quality of pasta that contained the nontraditional ingredients of soy and oat flours.

Materials and Methods

Materials

Commercial patent durum flour was obtained from the North Dakota Mill and Elevator, Grand Forks, ND. Soy flour and oat flour were obtained commercially from a local grocery store. Xanthan gum was procured from three different vendors (Cargill Texturizing Solutions, Wayzata, MN, USA; Sigma-Aldrich, St. Louis, MO, USA; Tic-Gums, White Marsh, MD, USA). Dextran standards were purchased from Sigma-Aldrich Corp. The gel permeation grade dextran standard molecular weights were as follows: 48,600, 147,600, 273,000, 409,800, 667,800, 1.4 million, and 5-40 million Da.

Flour blends were prepared by fortifying durum flour with soy flour and oat flour (10% w/w), and XG (2% w/w). Uniform blends were prepared by mixing ingredients for 5 min using a cross-flow blender (Patterson Kelly, East Stroudsburg, PA, USA). The 10% level of nontraditional ingredients was selected because previous research has indicated that 10% substitution of nontraditional ingredient generally had little or no effect on pasta quality (Marconi and Carcea 2001; Zhao et al 2005). For gums, the 2% represents the maximum amount that would be used. It is the amount that previous researchers had indicate would have a positive effect on pasta quality (Manthey and Sandhu 2008).

Characterization of Ingredients and Flour Blends

Particle size distributions of individual ingredients were determined using a Ro-Tap mechanical shaker (W.S. Tyler, Mentor, OH, USA) with US Standard sieves 30, 40, 60, 80 and 100 (600, 425, 250, 180 and <180 μm, respectively). A 100 g sample was run for 5 min. Each sample was evaluated in triplicate.

Bulk density of individual ingredients was measured using a test weight apparatus (Seedburo Equipment Co., Des Plaines, IL, USA). Material was poured into a standard one-quart container with excess material removed using a leveling stick in the manner used to determine test weight of grain. The weight of material per 0.95 L (1 quart) was converted to g/cm^3.

Individual ingredients were analyzed for moisture, ash and protein contents according to Approved Methods 44-15.02, 08-01.01 and 46-30.01, respectively (AACC International 2010). The conversion factor used to determine protein content was %N x 5.7 for wheat flour and %N × 6.25 for soy flour, oat flour, and XG. Lipid content was determined using a 16 hr Soxhlet extraction with hexane, according to Method Ba 3–38 (AOCS 1998). The pH of durum flour, soy flour and oat flour was determined according to Approved Methods 02-52.01 (AACC International 2010). Durum flour blends were analyzed for dough strength as measured by using mixograph (National Manufacturing, Lincoln, NE) according to Approved Method 54-40.02 (AACC International 2010).

Swelling Volume

Swelling volume of durum flour ingredients was determined using Approved Method 52-21.01 (AACC International 2010). Durum flour, soy flour, oat flour and blends were weighed (0.25 g) into pre-weighed centrifuge tubes. Distilled water (15 mL) was added to tubes containing sample and were mixed on a vortex mixer for 10 sec. Sample tubes were then placed

in a 70°C water bath for 4 min, vortex mixed for 20 sec, placed back in 70°C water bath for 6 min, and then transferred to a boiling water bath for 10 min, placed in cold water for 5 min followed by centrifugation at 3,500 revolutions per min (rpm) for 4 min. Supernatant was carefully removed with a transfer pipette and tubes were weighed to determine sediment weight. Swelling volume was calculated as follows:

$$\text{Swelling volume} = (\text{sediment weight})/(\text{dry sample weight}).$$

Approximate Water Holding Capacity

Approximate water holding capacities of durum flour, soy flour and oat flour were determined according to Approved Method 56-30.01 (AACC International 2010). For XG, Approved Method 56-30.01 was used with some modifications as described below. Xanthan gum samples were weighed (0.45 g than 1 g as indicated in the method) on) on an 'as-is moisture' (i.e., wet basis, wb) into a pre-weighed 50 mL centrifuge tubes (transparent polycarbonate). A small sample size was selected with an aim to get appropriate results due to the strong hydration capacity of gum. Distilled water was added in small increments and was stirred with glass rod after each addition until the sample was thoroughly wetted. Stirring rods were wiped on the sides of the tube. Samples were centrifuged (Beckman centrifuge) at 2,000 rpm for 1.5 hr and the supernatant removed and discarded. At least three replicates were performed for each sample. Approximate water holding capacity was calculated as:

$$\text{Approximate water holding capacity (mL/g)} = [(\text{tube weight}+\text{sediment weight})-(\text{tube weight}+0.45)]/0.45$$

Water Holding Capacity

Durum flour, soy flour, oat flour, and XG samples were each weighed into four tubes after calculating weight of the material according to the following formula

(Material weight =15/approximate water holding capacity +1),

where 15 is the desired total weight of the sample and water. The volume of water added to the first and second tubes were 1.5 and 0.5 mL more, respectively, and the volume of water added to the third and fourth tubes were 1.5 and 0.5 mL less, respectively, than the calculated volume of water (15 - material weight). Contents of the each tube were vigorously mixed with a stirring rod for 2 min and were centrifuged at 2,000 rpm for 1.5 hr. Any two adjoining tubes, one with minimum and one with maximum supernatant, represented the range in which water holding capacity value would occur. Water holding capacity was presented as true midpoint between volumes of these two tubes (e.g. volume of tube 1 and 2) divided by material weight.

Physicochemical Characterization of Xanthan Gum

Stock solutions (0.5%, w/v) of XG samples were prepared. Weight of the gum was calculated on an 'as-is moisture' (i.e., wet basis, wb). Xanthan gum from varied sources were weighed 1.25 g and were thoroughly dispersed in 250 mL volumetric flask containing 200 mL of doubly distilled water (ddH_2O) followed by addition of sodium azide salt (0.2% wt in 250 mL ddH_2O). Sodium azide salt was added with an aim to minimize the microbial growth. Gums were allowed to hydrate overnight at 4°C. Gum solutions were then continuously stirred at slow speed with a magnetic stirrer for 2 hr at ambient temperature. Volume was adjusted to 250 mL using

ddH_2O and was heated for 30 min at 75°C in a water bath to hydrate gums completely. Gum solutions were centrifuged at 2,000 rpm for 1.5 hr to separate the insoluble particles. Clear supernatant was collected and insoluble particles were oven dried at 105°C for 7 hr. Upon cooling, dried weight was recorded. Then difference in the weight of original gum sample and dried gum residue was determined, which was used to calculate true concentration of the stock solution as follows:

True concentration = [(original gum wt-dried gum residue)/volume of stock solution]*100

Stock solutions were stored at 4°C to minimize bacterial growth.

High Performance Size Exclusion Chromatography (HPSEC)

The initial stock solutions of XG samples from different sources were diluted 10 times with ddH_2O. Diluted solution was heated to 50°C, and stirred for 1 hr, and filtered warm through 0.45 µm syringe filters (nylon). A 20 µL volume of gum sample was injected into the Agilent HPLC 1200 series high-performance liquid chromatograph (Agilent Technologies, Wilmington, DE). Waters Ultrahydrogel linear column (7.8 mm x 300 mm) was used to separate the polysaccharides. HPLC grade water was used as mobile phase solvent at a flow rate of 0.4 mL/min at 40°C. An Agilent refractive index detector and PC with ChemStation (HP ChemSation for LC Rev. A.04.01) were used for control and integration. Samples were run in triplicate. Weight-averaged molecular weights were calculated using a series of gas permeation chromatography-grade dextrans.

Monosaccharide Composition

A method described by Blakeney et al (1983) was used to determine monosaccharide composition of XG samples. Method involved simple and rapid preparation of alditol acetates for monosaccharide analysis. The alditol acetate samples were analyzed on a Hewlet Packard 5890 series II Gas Chromatograh (GC) system with a Flame Ionization Detector (FID) (Agilent Technologies, Inc. Santa Clara, CA). Supelco SP-2380 fused silica capillary column (30 m×0.25 mm×0.2 μm) (Supelco Bellefonte, PA) was used to separate monosaccharides. The system parameters were as follows: injector and detector temperatures of 230°C and 250°C, respectively, flow rate of (the mobile phase gas, Helium) 0.8mL/min, flow pressure 82.7 kPa and oven temperature of 100°C.

Total Glucose Content

Total starch assay was used to determine total glucose content of XG samples. Total starch assay kit was used to determine percent total glucose content (TGlc) (% db) by Approved Method 76-13.01 (AACC International 2010) with slight modifications as described below. First, ethanol addition step was eliminated because its addition resulted in development of a thick gel like mass which prevented appropriate dilution of gum sample during analysis. Xanthan gum was interacting with OH-groups of methanol. Secondly, 10 mL of Na-acetate buffer was added to each gum sample (20 mg).

Rheological Measurements

The volume (v_1) of the stock solution required to prepare XG solutions (0.2, 0.3 and 0.4%, w/v) was calculated using formula

$$(m_1v_1=m_2v_2),$$

where m_1 is true concentration of the stock solution, m_2 is the required concentration of the solution and v_2 is the final volume of the solution that has to be made. Viscosities of XG samples from different commercial sources were determined at three different concentrations (0.2, 0.3 and 0.4% w/v) using a Stresstech controlled stress/strain rheometer (ATS Rheosystems, Bordentown, NJ) with parallel plates. The solutions were pipetted (0.3 mL) between the plates and evenly spread out and the gap was adjusted to 0.5 mm. A constant shear rate (1/s) of 1.006, 1.589, 2.513, 3.981, 6.304, 10, 15.83, 25.13, 39.55, 63.09, 100, 158.5, 251.2, 397.3, and 631 was used for analysis and the samples were run at 20°C. Samples were run in triplicate. Values obtained were the average of triplicates that were used to determine final viscosity per sample.

Pasta Processing

Blends (1.3 kg) were hydrated to 32% absorption (wb) with warm distilled water (40°C). The wetted ingredients were mixed at high speed in a Hobart mixer (Hobart Corp., Troy, OH, USA) for 4 min and placed in the mixing chamber of the pasta extruder. Mixing during hydration was done in 3 steps. First, water was added to the ingredients as mixing bowl paddles rotated at 60 rpm; second, mixing continued for 90 sec at 60 rpm; then paddle speed was increased and maintained at 180 rpm for 2 min. Total mixing time was 4 min.

The mixtures were extruded under vacuum as spaghetti using a DeMaCo semicommerical laboratory extruder (DEMACO, Melbourne, FL, USA). Extrusion conditions were: extrusion temperature, 45°C; mixing chamber vacuum, 46 cm of Hg; and screw speed, 25 rpm. The extrusion screw had a length to diameter ratio of 8.5:1, a constant root diameter and uniform pitch of the entire length of the screw.

Mechanical energy (ME; J/s), extrusion rate (ER; g/s), and extrusion pressure (EP; psi) were recorded during the extrusion of each sample. Specific mechanical energy (SME; J/g) was calculated as the ME/ER. The ME required to operate the empty pasta press was subtracted from the ME required to operate the press under load. After extrusion, spaghetti was dried in a laboratory pasta dryer using a high temperature (70°C) drying profile.

Spaghetti Color and Cooking Quality

Color of the spaghetti was determined by measuring CIE L-value, *a*-value, and *b*-value using a Minolta CR-310 Colorimeter (Minolta Corp., Ramsey, NJ). L-value represents brightness; *a*-value represents redness when positive and greenness when negative; and *b*-value represents yellowness when positive and blueness when negative.

Spaghetti (10 g) was cooked for 12 min in a glass beaker containing 300 mL boiling water. Cooking was performed using Method 66-50.01 (AACC International, 2010). Cooked samples were drained for 2.5 min and then weighed to measure cooked weight. Cooking loss (weight of total solids) was measured by evaporating cooking water to dryness in a forced-air oven at 110°C. The cooked samples were measured for their firmness using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA). Firmness was measured by the amount of work (g cm) required to shear five cooked strands of spaghetti using a pasta blade probe attached to the texture analyzer.

Experimental Plan and Statistical Analysis

The experimental design was a randomized complete block with factorial arrangement for fixed effects of nontraditional ingredients and XG sources. Three replicates were performed on each treatment. Each replicate was extruded on a separate day. Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute,

Cary, NC, Software. F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Results and Discussion

Characterization of Commercial Xanthan Gums

Physical Properties of Commercial Xanthan Gums

Bulk density, particle size distribution, and water holding capacity of XG differed depending on commercial source (Tables 17 and 18). Bulk density was greatest with XG1 (0.73 g/cm^3), intermediate with XG2 (0.69 g/cm^3), and lowest with XG3 (0.54 g/cm^3; $LSD_{0.05} = 0.01$). XG3 (99.7% < 149 μm) and XG1 (95.9% < 149 μm) particle size was fine than with XG2 (68.7% < 149 μm; Table 18). Bulk density is a function of particle weight and packing proportion, which is the percentage of volume that is occupied by the XG particle. Usually, bulk density increases as particle size decreases (Yansari et al 2004). Xanthan gum 1 and XG3 had similar particle size distribution, but XG1 had the highest bulk density while XG3 had the lowest. Xanthan gum 1 probably had more efficient packing due to particle shape and/or had greater particle weight.

Table 17. Mean values* for the physical and proximate analysis of xanthan gum from different vendors** are presented in the table.

Xanthan Gum Vendor	BD (g/cm)	WHC (mL/g)	TGlc (%)	Nitrogen (%)[a]	Ash (%)[a]
XG1	0.73a	15.10b	0.57c	0.78a	8.73c
XG2	0.69b	16.24a	2.56b	0.32b	12.60a
XG3	0.54c	16.20a	3.65a	0.76a	10.80b
LSD***	0.01	0.28	0.43	0.04	0.43

*Values followed by same letter are not significantly different at P=0.05.
**XG1=Xanthan gum from vendor 1, XG2=Xanthan gum from vendor 2, XG3=Xanthan gum from vendor 3, BD-Bulk density, WHC-Water holding capacity, TGlc-Total glucose content.
***Least significant difference, a-reported on 14% mb.

Table 18. Mean values for particle size distribution (%) of xanthan gum from different vendors*.

	Mesh Size µm						
	600	425	250	180	149	<149	
XG vendor							Total (g)
XG1	0.0	0.0	0.1	1.7	2.1	95.9	99.8
XG2	0.0	0.0	13.1	11.0	6.2	68.7	98.9
XG3	0.0	0.0	0.0	0.0	0.0	99.7	99.7

*XG1=Xanthan gum from vendor 1, XG2=Xanthan gum from vendor 2, XG3=Xanthan gum from vendor 3, n=3.

Xanthan gum 2 and XG3 had similar water holding capacity (16.24 and 16.20 mL/g, respectively) and both were greater ($LSD_{0.05}$ = 0.28) than that of XG1 (15.10 mL/g). Yansari et al (2004) and Zhu et al (2010) reported that water holding capacity was lower with fine particle size than with coarse fiber particles. Xanthan gum 2 had the coarsest particle size and a high water holding capacity. The high water holding capacity for XG3 might be related to its bulk density. Yansari et al (2004) showed that water holding capacity was greater with low bulk density.

The lower water holding capacity of XG2, while having fine particle size, appears to be a critical point in XG particle size, below and above which XG1 (most coarser particles) and XG3 (finest particles) had higher water holding capacities (Tables 17 and 18). Zhu et al (2010) reported that reduction the particle size has significant affect on the physical structure of the dietary fiber. Keithireddipalli et al (2002) reported that grinding dry fibrous material to fine powder might adversely affect its water holding capacity and swelling capacity. It is an affect that is not only attributable to the reduction in particle size but also to altering the fiber matrix structure. Similarly, higher and/or lower water holding capacities of XG (Table 17) from varied sources not merely seems to be a function of different particles size (Table 18) but also of a gum structure that might have altered the molecular weight of XG (Fig. 14), thereby altering the bulk density of XG (Table 17). Though XG2 had coarser particles and higher MWT than XG1 and

XG3 (Fig. 14), its lower bulk density compared to XG1 allowed XG2 to have lower XG particles per unit area. A lower number of XG2 particles per unit area would allow particles to have more space surrounding them to develop greater number hydrophilic linkages than XG1 particles which had higher bulk density value (Table 17). The enhanced water holding capacity of XG3 (having lowest bulk density) could be related to the surrounding spaces between particle that allow hydrophilic linkages between water and the XG. Though significantly similar ($LSD_{0.05}$ = 0.28), higher water holding capacity of XG2 (16.24 mL/g) than XG3 (16.20 mL/g) could be attributed to their particle size. The XG2 with coarser particles would had lower structural damage than XG3 having finest particles size.

Chemical Properties of Commercial Xanthan Gums

Results for nitrogen, ash, and total glucose contents of XG samples (Table 18) were similar to those published by (Gracia-Ochoa et al 2000a, b; Thacker et al 2010). These components are present as contaminants in XG. They come from nitrogen, carbon, amino acids, and mineral nutrient sources present in the medium that are used to grow *Xanthomonas* spp. culture (Garcia-Ochoa et al 2000b).

Nitrogen, ash, and glucose content of XG samples differed with commercial source (Table 17). Xanthan gum is produced commercially in batch production using glucose as substrate and N salts such as NH_4Cl or $NaNO_3$. NH_4 is a better N-source for biomass accumulation while NO_3 is best for XG yield (Rosalam and England 2006). Differences in the refining methods (of crude XG) used by manufacturers result in variation in the amount of these contaminants in XG (Thacker et al 2010; El-Enshasy et al 2011).

HPSEC profiles of the three XG samples are shown in Fig. 14. All XG samples displayed similar elution profiles. There were small differences in terms of elution times.

Xanthan gum 2 eluted earliest (11.48 min), followed by XG1 (11.61 min) and XG3 (11.64 min). Weight averaged molecular weight (MWT) of commercial xanthan gum samples were calculated using series of GPC grade dextran standards. The MWT were 7.74 x 10^6, 7.76 x 10^6, and 6.92 x 10^6 for XG1, 2 and 3, respectively. Molecular weight of XG has been reported to vary from 2 x 10 ^{6} to 20 x 10^6 (Palaniraj and Jayaraman 2011). Casas et al (2000) studied XG production under several operational conditions and its effect on XG molecular weight and rheological properties. They documented that molecular structure of XG varied with the fermentation time (10-50 hr) and temperature.

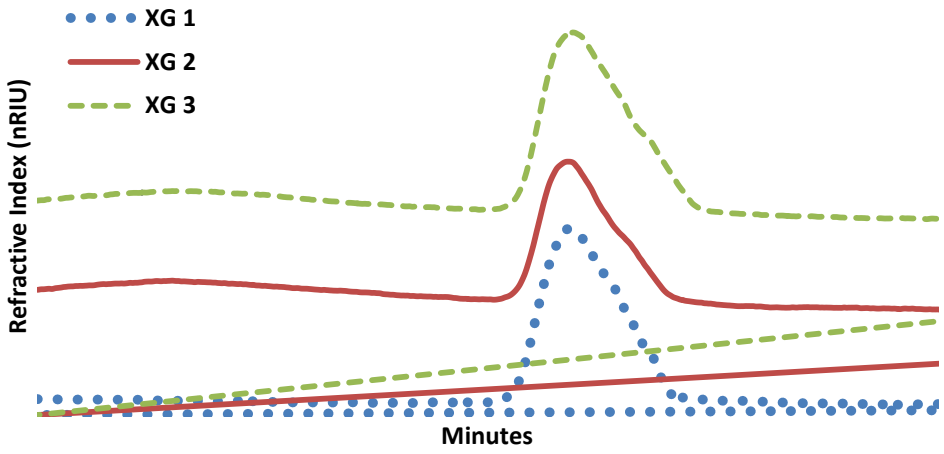


Fig. 14. High performance size exclusion chromatography profiles of xanthan gum from three different commercial sources. XG1- xanthan gum from vendor 1, XG2- xanthan gum from vendor 2 and XG3- xanthan gum from vendor 3.

Monosaccharide composition of the three XG samples after hydrolysis included glucose, mannose, and galactose. The concentration of the hydrolyzed sugars differed among the commercial sources. Monosaccharide compositions of XG were 64.7% glucose, 34.1% mannose and 1.2% galactose for XG1; 64.9% glucose, 33.9% mannose, and 1.2% galactose for XG2; and 54.5% glucose and 45.5% mannose for XG3. Galactose was not found in the XG3 sample. The

glucose and mannose content of XG3 was different from that of XG1 or XG2. Low concentration of galactose along with rhamnose, arabinose, xylose, has been detected in xanthan gum (Faria et al 2011). Occurrence of these minor sugars might be dependent on strain of *X.campestris* used during fermentation.

Viscosity of Commercial Xanthan Gum Solutions

Viscosity profiles of the three XG samples are shown in Fig. 15. Xanthan gum samples differed in magnitude but displayed similar viscosity profiles with each XG concentration. Xanthan gum viscosity varied among its commercial sources (Fig. 15) and graph exhibited typical shear thinning behavior. Xanthan gum 2 had the highest viscosity, XG1 had intermediate and XG3 had the lowest viscosity (Fig. 15). Viscosity results reflect the effect of MWT of XG (Fig. 14) on its rheological properties (Fig. 15). Xanthan gum 2, having higher MWT, produced high viscosity followed by XG1 and XG3. Results are well supported by research conducted by Casas et al (2000), who documented that at a given XG concentration, viscosity increased as average MWT of XG increased.

Characterization of Durum Flour and Nontraditional Ingredients

Protein content was greatest with soy flour (35.9 ±0.46%). Durum and oat flours had relatively low protein contents of 13.5±0.12 % and 12.4 ±0.20%, respectively. Lipid content was greatest with soy flour (22.1±0.17%), intermediate with oat flour (7.6±0.31%) and lowest with durum flour (1.1±0.00%). Protein and lipid contents of durum flour, soy flour, and oat flour were typical for each species (Doehlert and Moore 1997; Diaz et al 2008; Pednekar et al 2010). Dough pH ranged from 6.23±0.04 with oat flour, 6.30±0.06 with durum flour and 6.43±0.03 for soy flour. Swelling volume was greatest with oat flour (10.1±0.21 mL/g), intermediate with durum flour (7.1±0.85 mL/g) and lowest with soy flour (2.8±0.02 mL/g). Water holding capacity was

greatest with soy flour (1.5±0.04 mL/g), intermediate with oat flour (1.4±0.03 mL/g), and lowest with durum flour (0.9±0.01 mL/g). Water holding capacity seemed to relate with dietary fiber content. Based on the ingredient labels, soy flour had 10.7% dietary fiber, oat flour had 10% dietary fiber, and durum flour had 3.6% dietary fiber.

Bulk density was inversely related to lipid content and was greatest with durum flour (0.62±0.01 g/cm^3), intermediate with oat flour (0.52±0.08 g/cm^3) and lowest with soy flour (0.42±0.01 g/cm^3). The particle size distribution is presented in Table 19. Durum flour had the finest particle size with 87% of particles smaller than 250 µm. Soy and oat flours were coarser with 94 and 88% less than 600 µm but greater than 250 µm, respectively.

Table 19. Mean values for particle size distribution (%) of durum, soy and oat flours.

	Mesh Size, µm					
	600	425	250	180	<180	
Ingredients						Total (g)
Durum flour	0	0	12	42	45	99
Soy flour	5	35	59	1	0	100
Oat flour	2	22	68	5	2	99

n=3.

Dough Properties

All three XG samples increased dough strength (Fig. 16). Other researchers have reported that xanthan improved dough strength. Rosell et al (2001) reported that XG greatly improved dough strength. Brennan and Tudorica (2007) reported that XG contributed to structural strength of dough. Farinograph analysis has shown that XG increased water absorption, dough development time, and dough stability (Brennan and Tudorica 2007; Linlaud et al 2009). Extensiograph and alveograph analysis showed that xanthan gum reduced dough extensibility (Brennan and Tudorica 2007; Linlaud et al 2009).

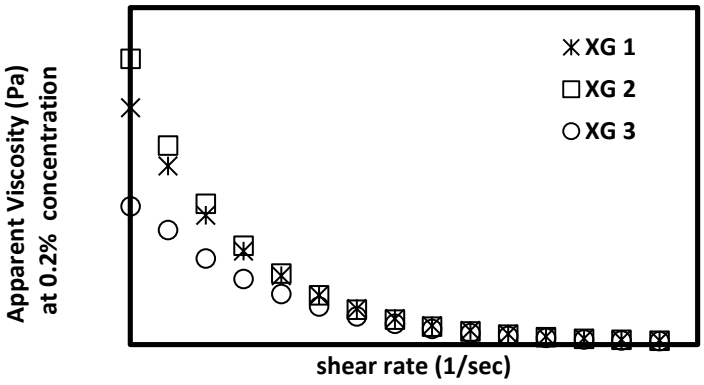


Fig. 15A

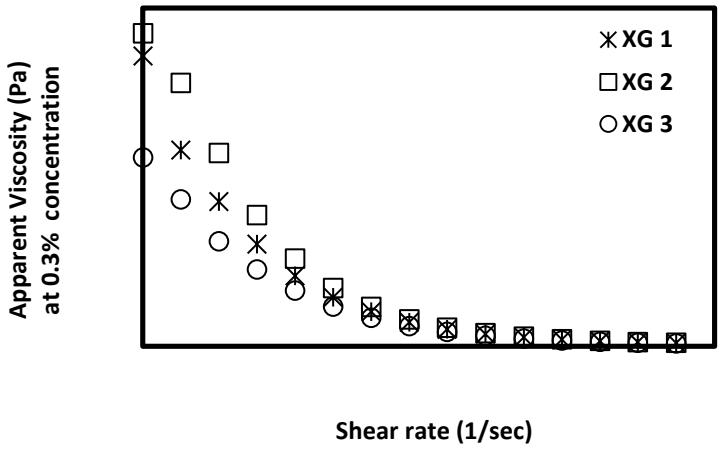


Fig. 15B

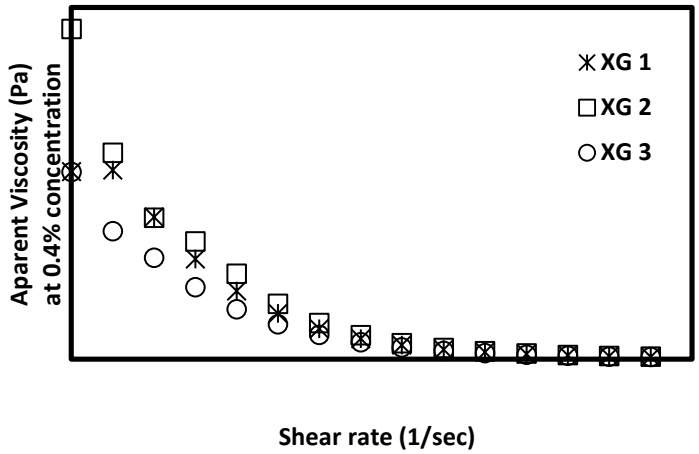


Fig. 15C

Fig. 15. Apparent viscosity (Pa) profiles of xanthan gums from vendors 1, 2 and 3 at three different concentrations. (A) 0.2% wt/v, (B) 0.3% wt/v, and (C) 0.4% wt/v.

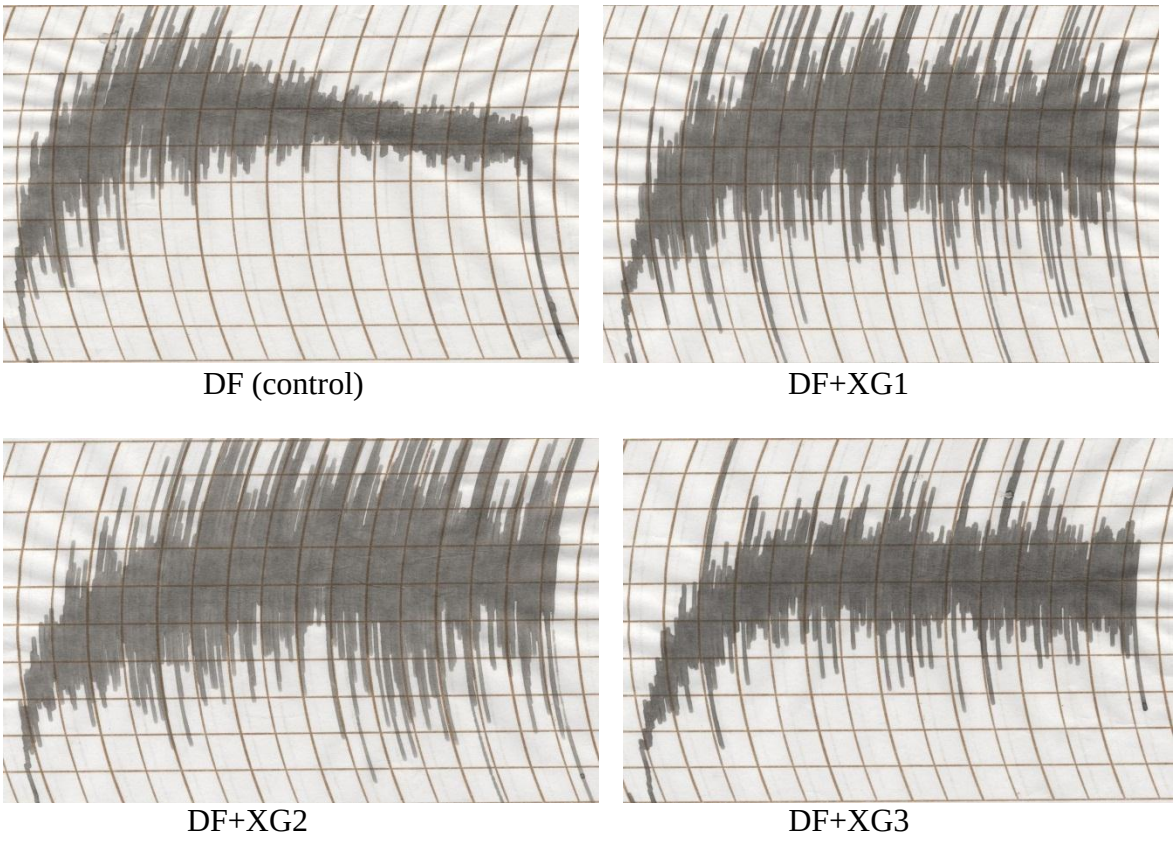
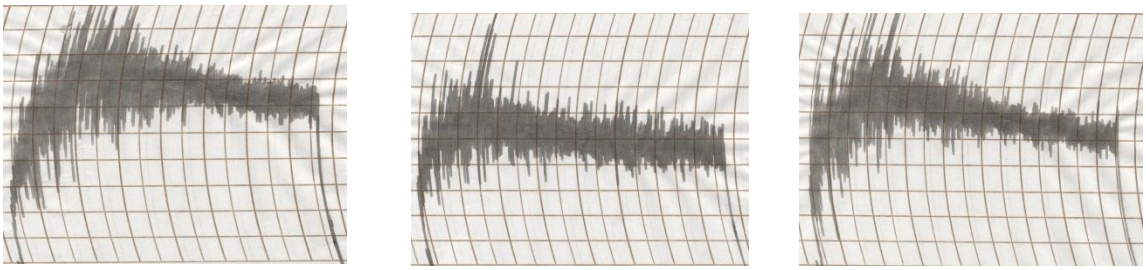


Fig. 16. The effect of xanthan gum vendor on the dough strength of durum flour containing xanthan gum. DF-Durum flour, XG-Xanthan gum from vendor 1, 2 and 3.

The level of increase in dough strength caused by XG varied with commercial source. For example, time-to-peak ranged from 2.75 to 4.25 min; peak width of the mixogram curve ranged from 2.5 to 3.75 BU; and end width ranged from 2 to 3 BU depending on the commercial source of XG. Xanthan gum 2 had the longest, while XG3 had the shortest time-to-peak. Time-to-peak often corresponds to the rate of hydration. Differences in XG samples might reflect their particle size. Xanthan gum 2 had the coarsest particle size. Large particles hydrate slower (slower rate of hydration and longer time to peak) than small particle size of XG3 and XG1 (Table 18). The midline height and band width of mixograms (indicators of dough strength) were

least with XG3. Dough strength results relate well with XG viscosity results (Fig. 15) where XG2 had highest viscosity, while XG3 had least viscosity.

Figure 17 shows typical mixograms of durum flour and its blends with soy flour and oat flour. Mixograms indicate that both soy flour and oat flour caused some reduction in dough strength. The soy flour and oat flour probably weakened the dough by physically interfering with gluten matrix and by restricting the amount of water available for gluten formation (Roccia et al 2009; Skendi et al 2009). Roccia et al (2009) reported that gluten was weakened due to the interference of soy proteins on gluten structure and the decline in water available for gluten formation. Soy protein competes with gluten for water needed for proper gluten network formation (Roccia et al 2009). Skendi et al 2009 found that β-glucans, which are found in oat and barley flour, can reduce dough strength by binding available water and disruption intermolecular associations of gluten protein.



DF (control) DF+SF DF+OF

DF-Durum flour, SF-Soy flour, OF-Oat flour

Fig. 17. The effect of soy flour and oat flour on durum flour dough strength.

The nontraditional ingredient x XG vendor interaction was not significant for any mixogram parameters (Table A17). The nontraditional ingredient main effect was significant for mixogram time-to-peak, peak height and end height (Table 20). As reported for nontraditional

ingredient without xanthan, the presence of soy flour and oat flour reduced dough strength, time-to-peak and peak height and end height of mixogram compared to durum flour alone (Fig. 17 and Table 20).

Table 20. Effect of nontraditional ingredients averaged over xanthan gum vendor on mean values* for mixograph parameters of durum flour blends.

Blends	TtPk (min)	PkHt (BU)	EndHt (BU)
Durum flour	3.24a	7.50a	7.30a
Durum flour+Soy flour	2.74b	6.90b	6.17b
Durum flour+Oat flour	2.91ab	6.80b	6.73ab
LSD**	0.42	0.27	0.89

*Values followed by same letter are not significantly different at *P*= 0.05.
**Least significant difference, BU-Brabender units, TtPk-Time-to-peak, PkHt-Peak height, EndHt-End height.

Xanthan gum vendor main effect was significant for mixogram peak height and end width (Table A17). Peak height ranged from 6.8 to 7.3 BU and peak width ranged from 2.2 to 3.2 BU respectively (Table 21). Peak height was greater both with XG2 and XG3 than XG1. XG3 had the highest fine particle size distribution (Table 18) and high water holding capacity (Table 17) and XG2 had the least fine particle size distribution (Table 18) and high water holding capacity (Table 17), thus results seem to reflect the water holding capacity and not the particle size of the XG. As discussed before in paper (in page 161-162), higher water holding capacities could be a function of XG particle bulk density as shown in Table 17. Xanthan gum with high water holding capacity could have prevented water from interacting with durum flour, reducing the moisture available for gluten/dough development. Dough strength is greatly affected by available moisture, because dough strength increases with decreased available water.

Table 21. Effect of xanthan gum vendor averaged over nontraditional ingredient on mean values* for mixogram parameter values.

Xanthan Gum Source	PkHt (BU)	End Width (mm)
XG1	6.81b	2.66ab
XG2	7.17a	3.22a
XG3	7.33a	2.22b
LSD**	0.27	0.90

*Values followed by same letter are not significantly different at *P*=0.05.
**Least significant difference, XG-Xanthan gum, BU-Brabender units, PkHt-Peak height.

Pasta Processing and Quality

Hydration of Ingredients

Durum flour was hydrated (32% absorption, wb) and mixed at 60 rpm for 2 min and at 180 rpm for 2 min, which resulted in small aggregates (3 to 5 mm dia.). The aggregates did not adhere to the sides of the mixing bowl or mixing paddles.

Hydration and mixing of durum flour + XG required slow mixing (60 rpm) for 2-3 min as compared to 4 min for durum flour. Hydrated ingredients became sticky and accumulated on the sides of the mixing bowl when mixed at 180 rpm or when mixed for more than 3 min. Over-mixing resulted in an extremely hard amorphous mass that had to be manually broken into small pieces before being placed in to mixing chamber of the extruder. These pieces were often extremely hard and were difficult to extrude. Large pieces had a tendency to block the flow of material into the extruder barrel. Blends with soy flour could only be hydrated and mixed at 60 rpm for no more than 2 min. Mixing longer than 2 min resulted in ingredient blends agglomerating and sticking to the wall of the mixing bowl. The hydrated durum flour + soy flour felt wet as compared to the hydrated durum flour. When hydrated to 32% moisture, it was

observed that both hydrated durum flour + soy flour and hydrated durum flour + soy flour + XG formed a slimy mass and free unbound water was observed in the blends. These observations indicate that soy flour blends required a lower hydration level (%) than the typical 32% hydration rate. Soy flour contained 22% lipid and 10.7% dietary fiber. The lipid portion would not hydrate while the dietary fiber portion would hydrate and bind water. For soy flour, the hydrophilic dietary fiber property probably did not offset the effect of lipid content on water binding and resulted in apparent over hydration.

Durum flour + oat flour and durum flour + oat flour + XG were hydrated and mixed at 180 rpm for 4 min. The hydrated ingredients formed aggregates that had a drier texture as compared to hydrated durum flour. Hydration did not appear to be uniform. Aggregates contained random patches of dry and wet particles. Oat flour contained 10 % dietary fiber. Fiber with or without XG would bind water, restricting water available to hydrate gluten proteins. Constituents of durum flour were left under-hydrated and over all blend looked dry.

Hydrated durum flour + oat flour + XG felt wetter than hydrated durum flour or hydrated durum flour + oat flour. However, hydrated durum flour + oat flour + XG was not as wet as hydrated durum flour + XG or hydrated durum flour + soy flour + XG. In a blend, nontraditional ingredient particles, gum particles and flour particles compete with each other for moisture as evident by their water holding capacities (Table 18). In blends containing XG, the XG hydrated rapidly and became over hydrated as compared to the treatment containing flour particles alone. Rapid rate of hydration of XG would be a result of its small particle size distribution and its high water holding capacity. Neither visual nor tactile assessment detected any differences associated with commercial source of XG on ingredient hydration.

Extrusion

Nontraditional ingredient x XG interaction was not significant for extrusion pressure, mechanical energy or specific mechanical energy but was significant for extrusion rate (Table A18). Xanthan gum did not affect extrusion rate of durum flour or durum flour + oat flour but did reduce the extrusion rate of durum flour + soy flour by 8.2% (data not presented).

Xanthan gum main effect was significant for extrusion pressure, mechanical energy, and specific mechanical energy (Table A18). Data indicated that the presence of XG resulted in higher extrusion pressure (596 vs. 485 psi), mechanical energy (263 vs. 214 J/sec) and specific mechanical energy (75.3 vs. 61.7 J/g). These results reflect the mixograph data where XG increased dough strength (Fig. 3). Development of strong dough by XG could account for the high water holding capacity of XG (15.1 to 16.2 mL/g) compared to durum flour (0.88 mL/g, Table 17). Higher water holding capacity of XG allows to bind and hold larger amounts of water than durum flour. It makes less water available to flour particles in a blend such that flour particles are left under hydrated and it eventually results in development of stronger dough.

Nontraditional ingredient x XG vendor interaction was not significant for any extrusion parameter measured (Table A19). Xanthan gum vendor main effect was significant for extrusion rate and specific mechanical energy, but not for extrusion pressure or mechanical energy. Extrusion rate was less with XG1 (3.5 g/sec) and XG2 (3.4 g/sec) than with XG3 (3.7 g/sec; $LSD_{0.05} = 0.2$). Results correlate with viscosity (Fig. 15) and dough strength (Fig. 16) findings of XG from different commercial sources where XG2 and XG1 had greater viscosity and dough strength compared to XG3. Conversely, specific mechanical energy was greater with XG1 (78.6 J/g) and XG2 (78.2 J/g) than with XG3 (69.1 J/g; $LSD_{0.05} = 4.5$). Since the mechanical energy

(J/sec) was not affected by XG source, the reduction in extrusion rate by XG1 and XG2 resulted in higher specific mechanical energy as compared to XG3.

Nontraditional ingredient main effect was significant for extrusion pressure, mechanical energy, and specific mechanical energy (Table A19). Extrusion pressure was reduced 29.1% by oat flour and 21% by soy flour; mechanical energy was reduced an average of 25.9% by both oat flour and soy flour; and specific mechanical energy was reduced an average of 25.3% by both oat flour and soy flour (Table 22). Extrusion rate was not affected by nontraditional ingredients. These results reflect the reduction in strength associated with dough containing soy flour and oat flour as determined by mixograph analysis (Fig. 16, Table 20).

Table 22. Effect of nontraditional ingredients averaged over xanthan gum vendor on mean Values* for extrusion parameter values.

Ingredients	EP (Psi)	ME (J/sec)	SME (J/g)
Durum flour	649 a	288 a	82.4 a
Soy flour	513 b	219 b	63.1 b
Oat flour	460 c	208 b	60.0 b
LSD**	41	23	7.3

*Values followed by same letter are not significantly different at *P*=0.05.
**Least significant difference, EP-Extrusion pressure, ME-Mechanical energy, SME-Specific mechanical energy.

Physical Quality

Spaghetti made only with durum flour was smooth to the touch. Spaghetti containing XG was slightly rough. Spaghetti made from durum flour + soy flour or durum flour + oat flour had a rough surface. White specks were visible on the surface of the different spaghettis that were fortified with XG. White specks were more pronounced with spaghetti made from durum flour + soy flour + XG or durum flour + oat flour + XG than with spaghetti made with durum flour + XG. White specks indicate improper, under-hydration of semolina particles.

Nontraditional ingredient x XG interaction was not significant for any of the color quality parameters (Table A20). Nontraditional ingredient main effect was significant for CIE L-value, *a*-value and *b*-value. Soy flour and oat flour reduced the L-value (57.9, 55.5 respectively vs 58.8 for durum flour) ($LSD_{0.05}$ = 0.49), *a*-value (5.5 and 4.8, respectively vs to 9.5 for durum flour) ($LSD_{0.05}$ = 0.39) and *b*-value (34.9 and 33.1, respectively vs 37.1 for durum flour) ($LSD_{0.05}$ = 0.36) of CIE color score for dry spaghetti. These results agree with those published by Zhao et al 2005; Baiano et al 2011; and Mitra et al 2012. Results indicate that fortification of nontraditional ingredients had negative impact on the brightness (L-value) and yellowness (*b*-value) of pasta.

Cooking Quality

Nontraditional ingredient by XG interaction was not significant for cooked weight, cooking loss and cooked firmness (Table A21). Xanthan gum main effect was significant for cooked weight and cooked firmness (Table A21). Compared to spaghetti without XG, spaghetti containing XG had greater cooked weight 32.7% compared to 31.1%/10 g dry spaghetti ($LSD_{0.05}$ = 0.3) and greater cooked firmness, 27.2 compared to 21.9 g/cm ($LSD_{0.05}$ = 1.5). Cooking loss from spaghetti was similar with or without XG and averaged to 7.0% (data not presented). These results are similar to those reported by Edwards et al (1995). They reported that XG (2%) increased cooked firmness but did not affect cooking loss. Brennan and Tudorica (2007) reported that xanthan gum increased cooked firmness. They attributed at least some of the increase in firmness to XG contributing to the structure strength.

Nontraditional ingredient main effect was significant for cooked weight, cooking loss and cooked firmness (Tables 23 and A22). Oat flour increased cooked weight, while soy flour decreased cooked weight relative to spaghetti made with only durum flour. Soy flour and oat flour pasta resulted in higher cooking losses than that of durum flour (control) pasta which had

lowest cooking losses. Cooking losses were highest in soy flour. Cooked firmness of spaghetti containing soy flour and only durum flour was similar. Oat flour reduced the cooked firmness. Mitra et al (2012) also reported that oat flour reduced cooked firmness of noodles. They attributed the decline in cooked firmness to oat flour interfering with gluten network and to the high water holding capacity of β-glucan. High firmness in soy flour pasta can be attributed its high protein content (35.9%). These results are similar to the results reported by Nasehi et al (2009) where fortification of full fat soy flour significantly decreased cooking time and cooked weight and increased cooking loss of spaghetti. Zhao et al (2005) evaluated seven different legume flours and reported that they increased both cooking loss and cooked firmness and had little effect on cooked weight.

Table 23. Effect of nontraditional ingredients averaged over xanthan gum vendors on mean cooking quality values*.

Blends	Cooked weight (%)	Cooking loss (%)	Cooked Firmness (gcm)
Durum flour	32.9b	6.5c	29.2a
Durum flour+Soy flour	31.7c	7.6a	27.5a
Durum flour+Oat flour	33.7a	7.0b	24.8b
LSD**	0.6	0.3	2.2

*Values followed by same letter are not significantly different at *P*=0.05.
**Least significant difference

Conclusion

Xanthan gum samples from different commercial sources differed in their physical and chemical attributes. In particular, they differed in the bulk density, particle size distribution, water holding capacity, weight average molecular weight, and dilute solution viscosity. The XG samples also differed in the degree that they increased dough strength and in their effect on extrusion rate and specific mechanical energy.

Although XG samples differed in the magnitude of their effect, they all resulted in a similar effect in terms of ingredient, flour, dough and pasta quality. Regardless of commercial source, XG increased dough strength of durum flour, increased extrusion quality parameters (except for extrusion rate) and increased cooked weight and cooked firmness of spaghetti, while nontraditional ingredients decreased the same. Extrusion rate, specific mechanical energy and cooked weight significantly varied among different commercial sources of XG. High concentration (10% w/w) and characteristic differences allowed nontraditional ingredients to have larger influence on the dough, processing and cooking quality than XG (2% w/w) in blends.

Differences in the performance of XG from varied sources in dough strength is significant from a commercial perspective. Extrusion rate and specific mechanical energy is highly dependent on dough strength and is an important factor in pasta processing plants. Extrusion rate and specific mechanical energy affects economical balance of commercial pasta company. Variability in XG functionality can therefore affect extrusion rate, specific mechanical energy and plant output. From research perspective, commercial source of XG probably does not matter because they all gave similar effect.

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OVERALL CONCLUSION

Semolina and durum flour were compared to study their effect on the quality of pasta containing nontraditional ingredients and gums. Characteristics and particle size distribution of semolina, durum, soy and oat flours were different relative to each other. Proximate analysis and particle size distribution of gums varied among each other and relative to semolina, durum, soy and oat flours. Granulation, gums and nontraditional ingredients had major impact on dough properties. Food gums had a bigger impact on time-to-peak with semolina than when with durum flour. Dough was stronger with semolina than with durum flour in 20 min mixogram. Stability of dough made with durum flour was improved by XG and GG but not by LBG. The effect of gums on dough strength was most pronounced with XG. Both oat flour and soy flour reduced dough strength but affected dough somewhat differently. Oat flour reduced peak height by 4.5% and end height by 6.9% and soy flour reduced peak height by 8.3% and end width by 5.3% and improved dough stability of durum flour (increased peak width-2.1% and end width-16.0%).

Results for the effect of gums and nontraditional ingredients on dough strength of semolina and durum flour were reflected in hydration properties of blends, physical quality of spaghetti and cooking quality. It indicates the significance of dough quality characteristics in preparation of pasta. Dough quality drives pasta quality. Overall, nontraditional pasta made with semolina had better quality over nontraditional pasta made with durum flour. There is no doubt that gums performed better and had much pronounced affect in durum flour than they had in semolina. It indicates importance of close proximity in the particle size of durum flour blends, which tended to enhance performance of particles during the hydration and dough making process. At the same time, durum flour nontraditional pasta was associated with higher cooking losses compared to semolina nontraditional pasta, which is undesirable from pasta quality

perspective. Based on these observations, it is concluded that in order to obtain good quality nontraditional pasta, the particle size should be in close proximity to semolina. However, if gums are used in the nontraditional pasta formula then durum flour over semolina is recommended. Durum flour was easier to handle/mix with gums due to similarity in particle size.

Each gum (GG, LBG and XG) were procured from three different vendors and were studied for their vendor effect on the physicochemical properties of gums and effect on the processing and cooking quality of nontraditional pasta. Physicochemical characteristics of GG varied among its vendors. Irrespective of vendor, hydration and mixing of durum flour containing GG required fast mixing (180 rpm) for short time (2-3 min). Hydrated blend felt dry as compared to hydrated durum flour. Guar gum generally increased strength of dough made with durum flour. The greatest increase in dough strength occurred with GG1 and GG2. Mixograms indicate that compared to durum flour alone, GG dough strength results seem to be related to GG viscosity results where GG1 and GG2 had higher viscosity than GG3 and was likely a function of GG molecular weight. Guar gum 1 and GG2, having higher molecular size, resulted in stronger dough compared to GG3 with smaller molecular size. Guar gum had no significant affect on the extrusion and cooking quality of pasta. Small differences in physicochemical characteristics of GG from different commercial sources had no significant affect on processing or cooking quality of pasta made from durum flour.

Similarly LBG characteristics significantly varied among samples from different vendors. There were measurable differences in particle size distribution, molecular size and viscosity of LBG. Viscosity of LBG varied among different concentrations and vendors. At lower concentration (0.2%), LBG1 had lowest viscosity and at higher concentrations (both 0.3% and 0.4%) it had highest viscosity. Locust bean gum 2 and LBG3 had consistent viscosity over

different concentrations (0.2, 0.3 and 0.4%, Fig 2A, B and C) where LBG3 always developed higher viscosity than LBG2. Regardless of commercial source, LBG increased dough strength of durum flour where LBG 2 increased dough strength the most. Irrespective of commercial source, hydration and mixing of durum flour containing LBG required slower mixing (60 rpm) for shorter time (2-3 min). Hydrated blend had wet texture compared to durum flour alone. LBG and its vendor sources had non-significant affect on the processing and cooking quality of pasta.

Xanthan samples from different vendors differed in physicochemical attributes. In particular, they differed in bulk density, particle size distribution, water holding capacity, weight average molecular weight, and dilute solution viscosity. The XG samples also differed in the degree that they increased dough strength and in their effect on extrusion rate and specific mechanical energy. Although XG samples differed in the magnitude of their effect, they all resulted in a similar effect in terms of ingredient, flour, dough and pasta quality. Regardless of commercial source, XG increased dough strength of durum flour, increased extrusion quality parameters (except for extrusion rate) and increased cooked weight and cooked firmness of spaghetti, while nontraditional ingredients decreased the same. Extrusion rate, specific mechanical energy and cooked weight significantly varied among different commercial sources of XG. High concentration (10 % w/w) and characteristic differences allowed nontraditional ingredients to have a larger influence on the dough, processing and cooking quality than XG (2% w/w) in blends.

It can be concluded that from the scientific research perspective, it does not matter from which commercial sources we purchased our gums (GG, LBG and XG) because they all end up in giving similar effect and differ in magnitude only. Gums (GG, LBG and XG) purchased from varied sources holds significance from the commercial or manufacturer's perspective. Guar gum

purchased from different vendors differed in performance towards dough strength that is significant from a commercial perspective. Extrusion rate is highly dependent on dough and is an important factor in pasta processing plants that drives production. In other words extrusion rate affects the economical balance of commercial pasta company. Variability in GG functionality can therefore affect extrusion rate and plant output. Locust bean gum from different vendors does affect the dough strength, but it did not seem to affect the processing and cooking quality of pasta. Xanthan gum samples differed in their magnitude of affect in dough quality, extrusion quality (extrusion rate and specific mechanical energy) and cooked weight of spaghetti. Different sources of XG can develop differences in the quality of the same product. Use of XG from one commercial source will bring more consistency in dough quality characteristics and subsequent quality of the product made.

FUTURE RESEARCH AND APPLICATION

Future research needs to be done to develop a technique, method or instrument, which would help us to determine the level of hydration of semolina or durum flour blends during the hydration process before pasta extrusion. Research also needs to be conducted to study the detailed hydration kinetics of semolina and durum flour blends when they are alone and with nontraditional ingredients and gums used for the preparation of nontraditional pasta. Investigations in physicochemical state of semolina/durum flour + nontraditional ingredient + gum blend components (for example starch, proteins, lipids and non starch polysaccharides) before and after the hydration is needed. It would help us identify the actual changes that take place in components of blend ingredients during the hydration process before extrusion.

Nontraditional ingredients used for nontraditional pasta making, for example soy and oat flour contains high level of lipid compared to semolina and durum flour. Hydrophobic lipid moieties tend to alter the hydration properties of semolina/flour blends. Future work needs to done to develop nontraditional pasta that contains defatted fractions of soy and oat flours. It will help in eradicating negative affect associated with lipid component during the hydration process in pasta making. It is of no doubt that all ingredients that would be used for nontraditional pasta needs to be of similar particle size for developing a good quality nontraditional pasta.

Guar gum, LBG and XG are most frequently used gums in different food systems where the use of dough is involved for the development of the final product. I explored these gums in nontraditional pasta system. Similarly, these gums could be explored in variety of other food systems to study their physicochemical effectiveness in developing that product.

Following my viscosity research related to GG, LBG and XG during my Ph.D, I fractionated these gums into different particle sizes and ran viscosity analysis using a Rheometer.

Viscosity profiles obtained from different gum fractions with varied particle sizes showed difference in their viscosity. It would be interesting to conduct a more detailed study in the future to determine why different particle size fractions of the same gum produced different viscosity results.

APPENDIX

Table A1. Analysis of variance for time-to-peak (min), peak height (BU), peak width (mm), end height (BU) and end width (mm), for the effect of granulation of semolina and durum flour on the quality of dough containing nontraditional ingredients and gums (xanthan, guar and locust bean gum).

Dependent variable	Sources of variation	Df	MS	*F*-value
Time-to-Peak	Rep	2	0.763	4.51
	Granulation (Gran)	1	1.25	7.41 *
	Nontraditional Ingredient (NTI)	2	0.702	4.15 *
	Gum	3	0.419	2.48
	Gran*NTI	2	0.944	5.58 *
	Gran*Gum	3	0.667	3.94 *
	NTI*Gum	6	0.518	3.06 *
	Gran*NTI*Gum	6	0.917	5.42 *
	Error	46	0.169	
Peak Height	Rep	2	0.074	0.87
	Granulation (Gran)	1	2.136	25.24 *
	Nontraditional Ingredient (NTI)	2	1.18	13.91 *
	Gum	3	0.688	8.13 *
	Gran*NTI	2	0.034	0.40
	Gran*Gum	3	1.01	11.95 *
	NTI*Gum	6	0.386	4.57 *
	Gran*NTI*Gum	6	0.356	4.20 *
	Error	46	0.085	
Peak Width	Rep	2	0.003	0.05
	Granulation (Gran)	1	0.281	4.27 *
	Nontraditional Ingredient (NTI)	2	0.618	9.40 *
	Gum	3	1.101	1.54
	Gran*NTI	2	0.24	3.67 *
	Gran*Gum	3	0.495	7.52 *
	NTI*Gum	6	0.108	1.64
	Gran*NTI*Gum	6	0.159	2.43 *
	Error	46	0.066	
End Height	Rep	2	0.083	0.81
	Granulation (Gran)	1	2.35	22.87 *
	Nontraditional Ingredient (NTI)	2	0.98	9.55 *
	Gum	3	0.56	5.46 *
	Gran*NTI	2	0.09	0.94
	Gran*Gum	3	0.53	5.13 *
	NTI*Gum	6	0.10	0.97
	Gran*NTI*Gum	6	0.19	1.88
	Error	46	0.103	

Table A1(continued). Analysis of variance for time-to-peak (min), peak height (BU), peak width (mm), end height (BU) and end width (mm), for the effect of granulation of semolina and durum flour on the quality of dough containing nontraditional ingredients and gums (xanthan, guar and locust bean gum).

Dependent variable	Sources of variation	Df	MS	F-value
End Width	Rep	2	0.034	1.87
	Granulation (Gran)	1	0.056	3.03
	Nontraditional Ingredient (NTI)	2	0.056	3.05
	Gum	3	0.06	3.40 *
	Gran*NTI	2	0.06	3.32
	Gran*Gum	3	0.009	0.50 *
	NTI*Gum	6	0.018	0.97
	Gran*NTI*Gum	6	0.038	2.07
	Error	46	0.018	1.87

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A2. Analysis of variance for cooked weight (g), cooking loss (g) and cooked firmness (gcm) of spaghetti made with semolina and durum flour containing nontraditional ingredients and gums (xanthan, guar and locust bean gum).

Parameter	Sources of variation	Df	MS	F-value
Cooked Weight	Rep	2	3.306	25.68
	Granulation (Gran)	1	5.723	44.46 *
	Nontraditional ingredient (NTI)	2	13.479	104.71 *
	Gum	3	7.791	60.53 *
	Gran*NTI	2	0.854	6.64 *
	Gran*Gum	3	0.563	4.38 *
	NTI*Gum	6	0.325	2.52 *
	Gran*NTI*Gum	6	0.324	2.53 *
	Error	46	0.128	
Cooking Loss	Rep	2	0.294	3.53
	Granulation (Gran)	1	25.68	308.79 *
	Nontraditional ingredient (NTI)	2	6.413	77.11 *
	Gum	3	0.042	0.51
	Gran*NTI	2	0.413	4.96 *
	Gran*Gum	3	0.117	1.41
	NTI*Gum	6	0.545	0.66
	Gran*NTI*Gum	6	0.033	0.39
	Error	46	0.083	
Cooked Firmness	Rep	2	35.368	10.80
	Granulation (Gran)	1	11.321	3.46 *
	Nontraditional Ingredient (NTI)	2	38.577	11.78 *
	Gum	3	265.546	81.06 *
	Gran*NTI	2	4.063	1.24
	Gran*Gum	3	1.754	0.54
	NTI*Gum	6	2.938	0.90
	Gran*NTI*Gum	6	5.930	1.81
	Error	46	3.276	

*significant at P=0.05; Df=degrees of freedom; and MS=mean square.

Table A3. Analysis of variance for mechanical energy (J/sec), extrusion rate (g/sec), specific mechanical energy (J/g) and extrusion pressure (Psi), for the effect of granulation of semolina and durum flour on extrusion quality of spaghetti containing nontraditional ingredients and gums (xanthan, guar and locust bean gum).

Dependent variable	Sources of variation	Df	MS	*F*-value
Mechanical Energy	Rep	2	5505	7.94
	Granulation (Gran)	1	28401	40.95 *
	Nontraditional Ingredient (NTI)	2	9458	13.64 *
	Gum	3	1584	2.28
	Gran*NTI	2	1015	1.46
	Gran*Gum	3	1530	2.21
	NTI*Gum	6	629	0.91
	Gran*NTI*Gum	6	1059	1.53
	Error	46	693	
Extrusion Rate	Rep	2	0.317	3.10
	Granulation (Gran)	1	5	44.07 *
	Nontraditional Ingredient (NTI)	2	0.27	2.63
	Gum	3	1.561	15.26 *
	Gran*NTI	2	1	12.75 *
	Gran*Gum	3	0.334	3.27 *
	NTI*Gum	6	0.108	1.06
	Gran*NTI*Gum	6	0.140	1.37
	Error	46	0.102	
Specific Mechanical Energy	Rep	2	24	0.19
	Granulation (Gran)	1	0.508	0.00
	Nontraditional Ingredient (NTI)	2	435	3.42 *
	Gum	3	1547	12.17 *
	Gran*NTI	2	392	3.08
	Gran*Gum	3	11	0.09
	NTI*Gum	6	77	0.61
	Gran*NTI*Gum	6	125	0.98
	Error	46	16	
Extrusion Pressure	Rep	2	8786	8.12
	Granulation (Gran)	1	15871	14.66 *
	Nontraditional Ingredient (NTI)	2	40414	37.33 *
	Gum	3	22901	21.15 *
	Gran*NTI	2	95553	8.82 *
	Gran*Gum	3	11908	11.0 *
	NTI*Gum	6	3702	3.42 *
	Gran*NTI*Gum	6	2360	2.18
	Error	46	1082	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A4. Mean values* for granulation by food gum and granulation by nontraditional ingredient interactions for extrusion pressure and extrusion rate.

	Extrusion Pressure, psi		Extrusion rate, g/sec	
	Flour	Semolina	Flour	Semolina
Food gum				
None	499 c	574 ab	3.4 ab	4.0 a
LBG	484 c	557 bc	3.2 bc	4.0 a
Xanthan	553 b	540 c	3.1 c	3.2 b
Guar	611 a	594 a	3.6 a	4.1 a
LSD**	27		0.30	
Nontraditional ingredient				
None	558 a	633 a	3.4 a	3.8 b
Oat flour	546 a	545 b	3.1 b	4.1 a
Soy flour	506 b	522 b	3.4 a	3.5 c
LSD**	31		0.26	

*Mean values followed by same letter are not significantly different at *P*=0.05.
**Least significant difference.

Table A5. Mean values* for food gum by nontraditional ingredient interaction for extrusion pressure.

	None	Oat flour	Soy flour
None	556 b	515B b	539 a
LBG	576 b	514B b	472 b
Xanthan	590 b	542B b	506 ab
Guar	659 a	610B a	539 a
LSD**	38		

*Mean values followed by same letter are not significantly different at *P*=0.05.
**Least significant difference.

Table A6. Analysis of variance for time-to-peak (min), peak height (BU), peak width (mm), end height (BU) and end width (mm) from mixograms of durum flour blends containing nontraditional ingredients and guar gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Time-to-Peak	Rep	2	1.0	15.21
	Nontraditional Ingredient (NTI)	2	0.147	1.97
	Vendor	2	0.040	0.54
	NTI*Vendor	4	0.008	0.11
	Error	16	0.074	
Peak Height	Rep	2	3.0	17.62
	Nontraditional Ingredient (NTI)	2	2.0	11.12 *
	Vendor	2	0.160	0.87
	NTI*Vendor	4	0.081	0.44
	Error	16	0.182	
Peak Width	Rep	2	0.760	10.73
	Nontraditional Ingredient (NTI)	2	0.174	2.46
	Vendor	2	0.147	2.09
	NTI*Vendor	4	0.077	1.09
	Error	16	0.071	
End Height	Rep	2	3.0	40.16
	Nontraditional Ingredient (NTI)	2	2.0	21.69 *
	Vendor	2	0.030	0.37
	NTI*Vendor	4	0.064	0.79
	Error	16	0.082	
End Width	Rep	2	0.250	11.58
	Nontraditional Ingredient (NTI)	2	0.671	31.06 *
	Vendor	2	0.133	6.18 *
	NTI* Vendor	4	0.041	1.89
	Error	16	0.021	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A7. Analysis of variance for extrusion pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec) and specific mechanical energy (J/g) for extrusion quality of durum flour with and without nontraditional ingredients and guar gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Extrusion Pressure	Rep	2	4405	4.74
	Nontraditional Ingredient (NTI)	2	48705	52.36 *
	Guar Gum	1	1525	1.64
	NTI*Guar Gum	4	470	0.51
	Error	10	930	
Mechanical Energy	Rep	2	326	0.93
	Nontraditional Ingredient (NTI)	2	8428	24.03 *
	Guar Gum	1	3.0	0.01
	NTI*Guar Gum	4	774	2.21
	Error	10	351	
Extrusion Rate	Rep	2	0.03	1.45
	Nontraditional Ingredient (NTI)	2	0.028	1.35
	Guar Gum	1	0.001	0.04
	NTI*Guar Gum	4	0.03	1.52
	Error	10	0.021	
Specific Mechanical Energy	Rep	2	11	0.38
	Nontraditional Ingredient (NTI)	2	0.206	26.61 *
	Guar Gum	1	768	0.01
	NTI*Guar Gum	4	107	3.70
	Error	10	29	
	Rep			

*Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A8. Analysis of variance for extrusion pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec) and specific mechanical energy (J/g) of extruded spaghetti made with durum flour containing nontraditional ingredients and guar gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Extrusion Pressure	Rep	2	3826.0	6.78
	Nontraditional Ingredient (NTI)	2	60629.0	107.44 *
	Vendor	2	39.0	0.07
	NTI*Vendor	4	51.0	0.09
	Error	16	564.0	
Mechanical Energy	Rep	2	1989.0	8.46
	Nontraditional Ingredient (NTI)	2	6668.0	28.34 *
	Vendor	2	54.0	0.23
	NTI*Vendor	4	108.0	0.46
	Error	16	235.0	
Extrusion Rate	Rep	2	0.053	2.05
	Nontraditional Ingredient (NTI)	2	0.024	0.92
	Vendor	2	0.112	4.30 *
	NTI*Vendor	4	0.012	0.47
	Error	16	0.026	
Specific Mechanical Energy	Rep	2	74.0	6.17
	Nontraditional Ingredient (NTI)	2	444.0	36.95 *
	Vendor	2	15.0	1.28
	NTI*Vendor	4	10.0	0.83
	Error	16	12.0	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A9. Analysis of variance for L-value, *a*-value and *b*-value of dry spaghetti made with durum flour containing nontraditional ingredients and guar gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
L-value	Rep	2	0.447	1.51
	Nontraditional Ingredient (NTI)	2	35.0	118.52 *
	Vendor	2	0.444	1.50
	NTI*Vendor	4	0.181	0.61
	Error	16	0.296	
a-value	Rep	2	0.013	0.37
	Nontraditional Ingredient (NTI)	2	54.0	1492.91 *
	Vendor	2	0.003	0.08
	NTI*Vendor	4	0.033	0.90
	Error	16	0.036	
b-value	Rep	2	0.405	2.38
	Nontraditional Ingredient (NTI)	2	26.0	151.04 *
	Vendor	2	1.0	7.91 *
	NTI*Vendor	4	0.630	3.69 *
	Error	16	0.170	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.
CIE L-value represents brightness; *a*-value represents redness when positive and greenness when negative; *b*-value represents yellowness when positive and blueness when negative.

Table A10. Analysis of variance for cooked weight (g), cooking loss (g), and cooked firmness (gcm) of spaghetti made with and without nontraditional ingredients and guar gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Cooked Weight	Rep	2	0.139	0.86
	Nontraditional Ingredient (NTI)	2	6.2	38.3 *
	Guar Gum	1	0.236	1.46
	NTI*Guar Gum	4	0.016	0.10
	Error	10	0.162	
Cooking Loss	Rep	2	0.282	3.02
	Nontraditional Ingredient (NTI)	2	2.01	21.45 *
	Guar Gum	1	0.196	2.10
	NTI*Guar Gum	4	0.014	0.15
	Error	10	0.093	
Cooked Firmness	Rep	2	1.95	1.45
	Nontraditional Ingredient (NTI)	2	30.16	22.43 *
	Guar Gum	1	2.93	0.09
	NTI*Guar Gum	4	0.123	1.45
	Error	10	1.345	

*Significant at P=0.05; Df=degrees of freedom; and MS=mean square.

Table A11. Analysis of variance for time-to-peak (min), peak height (BU), peak width (mm), end height (BU) and end width (mm) from mixograms of durum flour blends containing nontraditional ingredients and locust bean gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Time-to-Peak	Rep	2	0.312	3.90
	Nontraditional Ingredient (NTI)	2	0.284	3.56
	Vendor	2	0.038	0.48
	NTI*Vendor	4	0.108	1.35
	Error	16	0.080	
Peak Height	Rep	2	1.273	39.25
	Nontraditional Ingredient (NTI)	2	2.0	74.85 *
	Vendor	2	0.027	0.83
	NTI*Vendor	4	0.007	0.22
	Error	16	0.032	
Peak Width	Rep	2	0.112	1.67
	Nontraditional Ingredient (NTI)	2	0.117	1.73
	Vendor	2	0.011	0.17
	NTI*Vendor	4	0.062	0.92
	Error	16	0.067	
End Height	Rep	2	1.6	11.60
	Nontraditional Ingredient (NTI)	2	1.6	11.81 *
	Vendor	2	0.007	0.06
	NTI*Vendor	4	0.032	0.24
	Error	16	0.134	
End Width	Rep	2	0.321	4.54
	Nontraditional Ingredient (NTI)	2	0.701	9.92 *
	Vendor	2	0.301	4.26 *
	NTI*Vendor	4	0.011	0.15
	Error	16	0.071	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A12 . Analysis of variance for extrusion pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec), specific mechanical energy (J/g), of spaghetti made with and without nontraditional ingredients and locust bean gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Extrusion Pressure	Rep	2	2814.4	2.85
	Nontraditional Ingredient (NTI)	2	50104	50.74 *
	Locust Bean Gum	1	1458.2	1.48
	NTI* LBG	4	282	0.29
	Error	10	988	
Mechanical Energy	Rep	2	84	0.34
	Nontraditional Ingredient (NTI)	2	9862	40.26 *
	Locust Bean Gum	1	12	0.05
	NTI* LBG	4	415.3	1.70
	Error	10	245	
Extrusion Rate	Rep	2	0.03	1.74
	Nontraditional Ingredient (NTI)	2	0.02	0.97
	Locust Bean Gum	1	0.06	3.45
	NTI* LBG	4	0.05	2.55
	Error	10	0.02	
Specific Mechanical Energy	Rep	2	17.3	0.74
	Nontraditional Ingredient (NTI)	2	918.3	39.43 *
	Locust Bean Gum	1	25	1.08
	NTI* LBG	4	69.2	2.97
	Error	10	23.3	

*Significant at P=0.05; Df=degrees of freedom; and MS=mean square.

Table A13. Analysis of variance for pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec), specific mechanical energy (J/g), of extruded spaghetti made with durum flour containing nontraditional ingredients and locust bean gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Extrusion Pressure	Rep	2	1185.0	2.06
	Nontraditional Ingredient (NTI)	2	64496.0	112.27 *
	Vendor	2	6.0	0.01
	NTI*Vendor	4	584.0	1.02
	Error	16	574.0	
Mechanical Energy	Rep	2	555.0	2.38
	Nontraditional Ingredient (NTI)	2	9375.0	40.23 *
	Vendor	2	18.0	0.08
	NTI*Vendor	4	99.0	0.42
	Error	16	233.0	
Extrusion Rate	Rep	2	0.062	3.53
	Nontraditional Ingredient (NTI)	2	0.012	0.67
	Vendor	2	0.016	0.93
	NTI*Vendor	4	0.032	1.86
	Error	16	0.017	
Specific Mechanical Energy	Rep	2	8.0	0.50
	Nontraditional Ingredient (NTI)	2	810.0	52.11 *
	Vendor	2	12.0	0.79
	NTI*Vendor	4	7.0	0.47
	Error	16	16.0	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A14. Analysis of variance for L-value, *a*-value and *b*-value of dry spaghetti made with durum flour containing nontraditional ingredients and locust bean gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
L-value	Rep	2	0.193	1.02
	Nontraditional Ingredient (NTI)	2	42.0	222.62 *
	Vendor	2	5.0	25.41 *
	NTI*Vendor	4	0.838	4.47 *
	Error	16	0.187	
a-value	Rep	2	0.010	0.06
	Nontraditional Ingredient (NTI)	2	54.0	308.38 *
	Vendor	2	0.071	0.41
	NTI*Vendor	4	0.247	1.43
	Error	16	0.173	
b-value	Rep	2	1.0	3.71
	Nontraditional Ingredient (NTI)	2	34.0	122.52 *
	Vendor	2	4.0	14.60 *
	NTI*Vendor	4	0.407	1.46
	Error	16	0.279	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.
CIE L-value represents brightness; *a*-value represents redness when positive and greenness when negative; *b*-value represents yellowness when positive and blueness when negative.

Table A15. Analysis of variance for cooked weight (g), cooking loss (g) and cooked firmness (gcm), of spaghetti made made with and without nontraditional ingredients and locust bean gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Cooked Weight	Rep	2	0.06	0.62
	Nontraditional Ingredient (NTI)	2	8.2	87.04 *
	Locust Bean Gum	1	0.75	8.03 *
	NTI* Locust Bean Gum	4	0.08	0.83
	Error	10	0.09	
Cooking Loss	Rep	2	0.45	4.52
	Nontraditional Ingredient (NTI)	2	1.7	17.44 *
	Locust Bean Gum	1	0.18	1.82
	NTI* Locust Bean Gum	4	0.012	0.12
	Error	10	0.099	
Cooked Firmness	Rep	2	3.5	2.12
	Nontraditional Ingredient (NTI)	2	27.0	16.7 *
	Locust Bean Gum	1	6.77	4.19
	NTI* Locust Bean Gum	4	0.4	0.23
	Error	10	1.6	

*Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A16. Analysis of variance for cooked weight (g), cooking loss (g) and cooked firmness (gcm), of spaghetti made with durum flour containing nontraditional ingredients and locustbean gum from different vendors

Dependent variable	Sources of variation	Df	MS	*F*-value
Cooked Weight	Rep	2	0.260	0.98
	Nontraditional Ingredient (NTI)	2	14.0	54.56 *
	Vendor	2	0.077	0.29
	NTI*Vendor	4	0.280	1.06
	Error	16	0.264	
Cooking Loss	Rep	2	0.681	4.8
	Nontraditional Ingredient (NTI)	2	3.0	17.26 *
	Vendor	2	0.083	0.59
	NTI*Vendor	4	0.361	2.56
	Error	16	0.142	
Cooked Firmness	Rep	2	13.52	14.80
	Nontraditional Ingredient (NTI)	2	42.0	45.60 *
	Vendor	2	0.237	0.26
	NTI*Vendor	4	0.452	0.49
	Error	16	0.914	

*Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A17. Analysis of variance for time-to-peak (min), peak height (BU), peak width (mm), end height (BU) and end width (mm) from mixographs of durum flour blends containing nontraditional ingredients and xanthan gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Time-to-Peak	Rep	2	0.940	5.30
	Nontraditional Ingredient (NTI)	2	0.556	3.13 *
	Vendor	2	0.176	0.99
	NTI* Vendor	4	0.015	0.08
	Error	16	0.177	
Peak Height	Rep	2	0.725	9.58
	Nontraditional Ingredient (NTI)	2	1.227	16.22 *
	Vendor	2	0.647	8.55 *
	NTI* Vendor	4	0.043	0.56
	Error	16	0.076	
Peak Width	Rep	2	0.450	2.65
	Nontraditional Ingredient (NTI)	2	0.456	2.65
	Vendor	2	0.358	2.11
	NTI* Vendor	4	0.092	0.54
	Error	16	0.169	
End Height	Rep	2	0.267	0.33
	Nontraditional Ingredient (NTI)	2	2.834	3.54 *
	Vendor	2	0.682	0.85
	NTI* Vendor	4	0.786	0.98
	Error	16	0.799	
End Width	Rep	2	0.964	2.41
	Nontraditional Ingredient (NTI)	2	0.471	0.58
	Vendor	2	2.259	2.78 *
	NTI* Vendor	4	0.352	0.43
	Error	16	0.814	

* Significant at P=0.05; Df=degrees of freedom; and MS=mean square.

Table A18. Analysis of variance for extrusion pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec) and specific mechanical energy (J/g) of spaghetti made with and without nontraditinal ingredients and xanthan gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Pressure	Rep	2	3014	2.96
	Nontraditional Ingredient (NTI)	2	57109	55.99 *
	Xanthan Gum	1	56076	54.98 *
	NTI*Xanthan Gum	4	441	0.43
	Error	10	1020	
Mechanical Energy	Rep	2	170	0.51
	Nontraditional Ingredient (NTI)	2	11482	34.62 *
	Xanthan Gum	1	10756	32.43 *
	NTI*Xanthan Gum	4	566	1.70
	Error	10	332	
Extrusion Rate	Rep	2	0.007	0.32
	Nontraditional Ingredient (NTI)	2	0.003	0.13
	Xanthan Gum	1	0.001	0.02
	NTI*Xanthan Gum	4	0.117	5.46 *
	Error	10	0.021	
Specific Mechanical Energy	Rep	2	21	0.64
	Nontraditional Ingredient (NTI)	2	883	27.41 *
	Xanthan Gum	1	829	25.72 *
	NTI*Xanthan Gum	4	68	2.10
	Error	10	32	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square

Table A19. Analysis of variance for extrusion pressure (psi), mechanical energy (J/sec), extrusion rate (g/sec) and specific mechanical energy (J/g) of spaghetti made with durum flour containing nontraditional ingredients and xanthan gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Pressure	Rep	2	1805	1.23
	Nontraditional Ingredient (NTI)	2	85989	58.72 *
	Vendor	2	1530	1.04
	NTI*Vendor	4	1491	1.02
	Error	16	1464	
Mechanical Energy	Rep	2	1505	5.46
	Nontraditional Ingredient (NTI)	2	14681	53.27 *
	Vendor	2	699	2.54
	NTI*Vendor	4	215	0.78
	Error	16	275	
Extrusion Rate	Rep	2	0.008	0.22
	Nontraditional Ingredient (NTI)	2	0.182	4.81 *
	Vendor	2	0.187	4.94 *
	NTI*Vendor	4	0.035	0.93
	Error	16	0.037	
Specific Mechanical Energy	Rep	2	165	8.33
	Nontraditional Ingredient (NTI)	2	700	35.14 *
	Vendor	2	257	12.92 *
	NTI*Vendor	4	12	0.59
	Error	16	20	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A20. Analysis of variance for, L-value, *a*-value and *b*-value of dry spaghetti made with durum flour containing nontraditional ingredients and xanthan gum from different commercial sources.

Dependent variable	Sources of variation	Df	MS	*F*-value
L-value	Rep	2	0.746	3.11
	Nontraditional Ingredient (NTI)	2	26	110.11 *
	Vendor	2	1	4.45 *
	NTI* Vendor	4	0.009	0.04
	Error	16	0.239	
a-value	Rep	2	0.043	0.29
	Nontraditional Ingredient (NTI)	2	59	396.78 *
	Vendor	2	0.09	0.61
	NTI* Vendor	4	0.018	0.13
	Error	16	0.149	
b-value	Rep	2	3	16.80 *
	Nontraditional Ingredient (NTI)	2	36	267.11 *
	Vendor	2	0.076	0.56
	NTI* Vendor	4	0.148	1.09
	Error	16	0.135	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.
CIE L-value represents brightness; *a*-value represents redness when positive and greenness when negative; *b*-value represents yellowness when positive and blueness when negative.

Table A21. Analysis of variance for cooked weight (g), cooking loss (g) and cooked firmness (gcm) of spaghetti made with and without nontraditinal ingredients and xanthan gum.

Dependent variable	Sources of variation	Df	MS	*F*-value
Cooked Weight	Rep	2	0.157	1.53
	Nontraditional Ingredient (NTI)	2	6.3	61.40 *
	Xanthan Gum	1	11.9	115.92 *
	NTI* Xanthan Gum	4	0.037	0.37
	Error	10	0.103	
Cooking Loss	Rep	2	0.403	4.51
	Nontraditional Ingredient (NTI)	2	1.9	21.12 *
	Xanthan Gum	1	0.001	0.10
	NTI* Xanthan Gum	4	0.039	0.30
	Error	10	0.089	
Cooked Firmness	Rep	2	2.3	1.12
	Nontraditional Ingredient (NTI)	2	27.7	13.59 *
	Xanthan Gum	1	127.7	62.75 *
	NTI* Xanthan Gum	4	0.816	0.40
	Error	10	2.0	

* Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.

Table A22. Analysis of variance for cooked weight (g), cooking loss (g) and cooked firmness (gcm) of spaghetti made with durum flour containing nontraditional ingredients and xanthan gum from different vendors.

Dependent variable	Sources of variation	Df	MS	*F*-value
Cooked Weight	Rep	2	0.646	2.01
	Nontraditional Ingredient (NTI)	2	9	27.23 *
	Vendor	2	1.180	3.68 *
	NTI* Vendor	4	0.666	2.08
	Error	16	0.321	
Cooking Loss	Rep	2	0.573	5.78
	Nontraditional Ingredient (NTI)	2	3.004	30.30 *
	Vendor	2	0.010	0.10
	NTI* Vendor	4	0.034	0.30
	Error	16	0.099	
Cooked Firmness	Rep	2	16	3.07
	Nontraditional Ingredient (NTI)	2	45	9.01 *
	Vendor	2	0.366	0.07
	NTI* Vendor	4	9	1.86
	Error	16	5	

*Significant at *P*=0.05; Df=degrees of freedom; and MS=mean square.