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Onderi, Meshack, O. ***Effects of Xanthan Gum and Added Protein on the Physical Properties of Gluten-Free Pizza Dough–A Texture Characterization Study Using Instron Model 3342***

Abstract

Gluten, an essential structure-binding protein is responsible for pizza crust quality. Although important, gluten causes health problems to celiac disease sufferers. Thus, the aim of this study was to develop a pizza crust using a gluten-free composite flour, xanthan gum and dairy ingredients. The study was conducted in two phases: first phase, xanthan gum at levels 0-5% was incorporated into the gluten-free flour composite. Dough was made and sheeted before being evaluated by physical methods compared to wheat dough. Then an optimum xanthan gum concentration was selected. Second phase, the selected 2% xanthan gum together with composite flour was mixed with dairy ingredients at 1-3% whey protein or 5-15% nonfat dry milk. Dough was made and sheeted then evaluated for physical properties. It was observed that xanthan gum successfully replaced gluten with 2% xanthan gum giving sheetable pizza crusts with optimum strength and extension. Together with 2% xanthan gum, dairy ingredients incorporation softened and increased the extension length of the pizza crust dough. A combination of 2% xanthan gum with 2% whey protein or 5% nonfat dry milk gave optimum dough performance in handling and processing. However, whey proteins had critical thresholds above which they increased dough resistance to puncture.

Acknowledgements

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Chapter l: Introduction

Pizza is a universally popular and important food product with its origins traced to the Naples region in Italy (Ensminger, Ensminger, Konlande, & Robson, 1995). The Webster's new world college dictionary (2010) defines Pizza as a baked Italian dish made of flattened bread dough topped with various herbs, fresh vegetables and meats. In the United States, pizza is typically topped with tomato sauce, grated cheese, and, often includes toppings such as sausage, mushrooms, and pepperoni. According to Mama Deluca's pizza (2011), Americans eat approximately 100 acres of pizza each day, or about 350 slices per second and approximately three billion pizzas are sold in the United States each year. Pizza consumption has increased 150% between 1977-78 and 1994. Total pizza sales increased 25% from 1991–1995 with a market value of $22.2 billion in 1995 (Progressive Grocer, 1996). According to USDA (2000), pizza consumption has more than tripled since the late 1970's and is likely responsible for the most significant share of sauces and cheese used and purchased in fast food restaurants.

Traditionally, the flattened bread dough of pizza crust is made from wheat flour. Wheat is also popularly used to make other baked products such as pasta, bagels, breakfast cereals, and bread. Wheat is a preferred ingredient in baked goods, including leavened breads and pizza bread, because of its ability to form a cohesive dough with the ability to trap gas and allow for mechanical sheeting (Landillon, Cassan, Morel, & Cuq, 2008; Letang, Piau, & Verdier, 1999). Wheat gluten is responsible for the formation of gas pockets and allowing for sheeting. This unique property of gluten makes wheat essential for the commercial production of light and leavened products such as bread and pastry (Belton, Colquhoun, Field, Grant, Shewry, Tatham, & Wellner, 1995; Schober, Messerschmidt, Bean, Park, & Arendt, 2008; Sivam, Sun-Waterhouse, Quek, & Perera, 2010).

Gluten is a protein present in wheat, and triticale grains. Wheat dough properties of molding as a loaf or sheeting are dependent on these gluten proteins which form a continuous proteinaceous network or matrix in the dough (Huebner & Wall, 1976; Payne, Corfield and Blackman, 1979). Gluten protein in wheat starch, upon hydration, forms a continuous viscoelastic network during dough development (Shewry, Popineau, Lafiandra and Belton, 2001; Juliano, 1985) that confer wheat dough its characteristic mechanical properties.

Gluten-containing products have been associated with Celiac disease, a type of food sensitivity, in humans (Mayo Clinic, 2010; Wieser & Koehler, 2008). Celiac disease is characterized by the destruction of the inner epithelial lining of the lumen (Raymond et al., 2006) and severely affects intestinal absorption leading to extensive malnutrition (Davidson & Bridges, 1987). Ingestion of gluten containing foods induces an immune response which includes binding of gluten peptides to human leukocyte antigens of presenting cells and the subsequent stimulation of T-cells accompanied by the release of proinflammatory cytokines such as interferon-γ and the activation of matrix metalloproteinases. This eventually results in mucosal destruction and epithelial apoptosis (Wieser & Koehler, 2008). Celiac disease affects at least 3 million people in the United States. The University of Chicago Celiac Disease Center (2011), estimates that 97% of the Celiac disease population in the United States currently remains undiagnosed. Celiac disease sufferers manage the conditions by avoiding foods containing gluten proteins and may have to adopt a strictly gluten-free protein diet.

There is an emerging need to develop gluten-free baked foods to enhance food choice of celiac-sufferers as well as consumers that demand gluten-free foods to address personal choices. According to Sloan (2011), gluten-free foods are a fast-emerging market and sales of gluten-free food products reached $2.9 billion in 2010. However, a technical challenge that presents in the development of gluten-free food products is the loss of material properties such as sheeting and leavened characteristics that are expectations among processors and consumers.

There are many sources of gluten-free starches (flours) such as potato, tapioca, sorghum, chickpea, quinoa, corn, and rice. However, each of these gluten-free flours lacks the protein (specifically gluten) necessary for the viscoelastic characteristic of the developed dough. Simulation of gluten functionalities in this gluten-free dough is achieved by addition of alternative proteins and hydrocolloids in order to attain a gluten-free dough with increased elasticity and improved gas retention (Christianson et al., 1974; Collar et al., 1999; Sánchez et al., 1996).

In bread making, there is a direct correlation between dough handling ability and final loaf quality (Shewry, Tatham, Barro, Barcelo, & Lazzeri, 1995). However, the predictability of baking performance in gluten-free dough related to sheeting has not been studied previously. Also, most of the gluten-free studies relating to textural properties have been on bread loaf quality after replacing gluten with hydrocolloids and proteins (Clelici & El-Dash, 2006; Huang & Preston, 1998; Kadan & Phillippi, 2007; Kulp, Hepburn, & Lehmann, 1974; Nishita, Roberts, & Bean, 1976; Ohtsubo, Toyoshima, & Okadome, 2009). There is sparse scientific and published literature on the effect of hydrocolloids and proteins on the textural properties of gluten-free flat breads that are sheeted during commercial manufacturing. Textural properties information on dough elongation and the ability to hold together while spreading is important for gaining insight into sheeting characteristics in the product and process development stages.

The basis of this study was to characterize physical properties of Cassava, Sorghum, and Chickpea (CSC) dough system by understanding dough textural behavior as related to sheeting process in pizza crust preparation before baking. Textural behavior was characterized by use of an Instron machine (model 3342, Instron EXTRA, Norwood, MA) to perform Textural Profile Analysis (TPA), elongation and puncture tests. The performance of gluten-free dough was compared to wheat dough because consumer expectations of the final pizza crust would be greatly influenced by conventional wheat pizza crust attributes.

Problem Statement

The effect of hydrocolloids and proteins on the textural properties of gluten-free flat breads is not understood very well and the predictability of gluten-free dough related to sheeting has not been studied previously. The main flaw in gluten-free doughs is that they are soft and batter-like which typically requires baking in pans (Cauvain, 1998), whereas pizza dough is rolled to sheets before baking, making it a critical step in dough handling and final product quality. Hence, the goal of this study was to characterize the textural properties of the CSC dough system by understanding dough textural behavior as related to sheeting process in pizza crust preparation before baking.

Purpose of the Study

The purpose of this study was to determine the effect of Xanthan Gum addition (1, 2, 3 and 5% by weight of ingredients excluding water) on the textural characteristics of gluten-free pizza dough made from Cassava, Sorghum and Chickpea (CSC) flour blends. Two percent xanthan gum in CSC dough was used to determine the effect of ingredients (whey protein at 1, 2 and 3% or dried skimmed milk powder at 5, 10 and 15% by weight of dry ingredients excluding water) on the textural characteristics on gluten-free pizza crust containing xanthan; at the Food and Nutrition Department, University of Wisconsin-Stout during the spring and summer semesters, 2011.

Assumptions of the Study

The major assumptions were:

- That xanthan gum together with dairy proteins could replace gluten in a gluten-free pizza crust.
- The physical properties tested were conducted on the raw gluten- free dough and it was assumed that the acquired quality attributes due to use of xanthan gum and dairy proteins were transferable to the final cooked product.
- Yeast was not used in preparation of samples due to lack of control of dough rise between different sample measurements. Therefore, it was assumed that excluding yeast from the ingredients would not interfere with the final product quality in scale up product processing where yeast would eventually be used.
- Finally, it was assumed that differences due lag time between sample measurements were not large enough to be expressed in the measured outcomes.

Objectives

The objectives of the study were to:

- Determine the effect of Xanthan Gum addition (1, 2, 3, 5% weight of total ingredients excluding water) on the textural characteristics of gluten-free pizza dough made from Cassava, Sorghum and Chickpea (CSC) flour blends.
- Determine the effect of added ingredients (whey protein at 1, 2 and 3% concentrations or dried skimmed milk powder at 5, 10 and 15% concentrations, weight of total ingredients excluding water) on the textural characteristics of gluten-free pizza crust containing 2% xanthan.

Hypotheses

The hypotheses of the study were:

- There is no significant difference in dough elongation, puncture and Texture Profile Analysis between CSC gluten-free dough at different Xanthan gum concentrations.
- There is no significant difference in dough elongation, puncture and Texture profile Analysis of CSC gluten-free dough containing 2% Xanthan gum with added whey protein (1, 2 and 3% concentrations, total weight excluding water) or dried skimmed milk powder (5, 10 and 15% concentrations, total weight excluding water).

Definition of Terms

Adhesiveness. Is the work required to overcome the attractive forces between the surface of the food and the surface of other materials in contact with the food.

Celiac disease or celiac sprue. Is an inflammatory disorder of the upper small intestine that prevents it from absorbing essential nutrients and is triggered by the ingestion of wheat, rye, barley, oat and other products (Wieser & Koehler, 2008).

Chewiness. Is the energy required to chew a solid food to the state required for safely swallowing it.

Cohesiveness. Is the strength of internal bonds making up the food product.

Gluten. Is a composite protein that is present in foods processed from wheat and related grains such as rye and barley. This composite protein is made of two fractions, glutenin and gliadin (Khan & Bushuk, 1979).

Gluten-free. Refers to diets or foods that exclude gluten containing sources.

Gumminess. Is the energy required to disintegrate a semi-solid food to a point ready for safely swallowing it.

Hardness. Is the force required to compress a food between the molars.

Hydrocolloids. Commonly named as gums are diverse range of biopolymers derived from natural sources that form a gel with water (Rosell et al., 2007).

Symbols and Acronyms

CMC - CarboxyMethyl Cellulose

CSC - Cassava, Sorghum and Chickpea

GF - Gluten Free

HPMC - HydroxyPropyl MethylCellulose

IgE - Immunoglobulin E

NFDM - Non Fat Dried Milk

SDS-PAGE - Sodium Dodecyl Sulfate-PolyacrylAmide Gel Electrophoresis

TPA - Texture Profile Analysis

C1 - Control 1

C2 - Control 2

C3 - Control 3

E1 - 1% xanthan Gum

E2 - 2% xanthan gum

E3 - 3% xanthan gum

E4 - 5% xanthan gum

W1- 1% whey protein

W2 - 2% whey protein

W3 - 3% whey protein

NFDM1 - 5% nonfat dry milk

NFDM2 - 10% nonfat dry milk

NFDM3 - 15% nonfat dry milk

Limitations

The major limitations of the study were:

- The timing of four months was not adequate to study the effects of xanthan gum and added proteins on both raw gluten-free dough and finished baked product. Therefore, only unbaked gluten-free dough was studied.
- Gluten-free dough was very fragile therefore giving difficulties in physical measurements and therefore needed longer measurement times and a lot of practice in order to minimize equipment measurement errors.

Chapter II: Literature Review

In this chapter, gluten, xanthan gum, gluten-free products and dairy ingredients are discussed to give an overview of past, current and future trends on the topic of this dissertation.

Gluten

Origin. Wheat gluten was isolated and first described by Jacopo Beccari in 1745. He reported that gluten could be prepared by washing the starch and water-soluble components of flour from wheat dough by kneading the dough under a gentle stream of water (Khan & Bushuk, 1979; Hargreaves, Popineau, Marion, Lefebvre, & Le Meste, 1995; Bloksma & Bushuk, 1998). The gluten preparation process also showed that wheat flour could be divided into two fractions, one which was water insoluble and similar to substances of animal origin and the other water soluble with characteristics similar to sugars (Shewry et al., 1995).These fractions were named amylo and glutinis, and correspond to what we presently call starch and gluten respectively. The insoluble residual (gluten) viscoelastic mass was later shown to contain about 80% of total protein of the wheat flour. Approximately two thirds of the mass of gluten is water of hydration. Dry solids contain 75-85% proteins and 5-10% lipids. Occluded starch makes up the rest of the dry matter (Khan & Bushuk, 1979).

As early as the 1750's, Gluten's importance in bread making was well established and recognized due to its contribution to the functional properties to wheat dough (Shewry et al., 1995). The historical importance of gluten is also evidenced in leavened bread making which is one of humankind's oldest forms of biotechnology established in ancient Egypt before 2000 BCE (Shewry et al., 1995). Other historical forms of gluten-based breads that have been made from wheat flour include flat breads (e.g., Indian origin) and pocket breads (Middle East), noodle (China and S.E Asia) and pasta (Shewry et al., 1995).

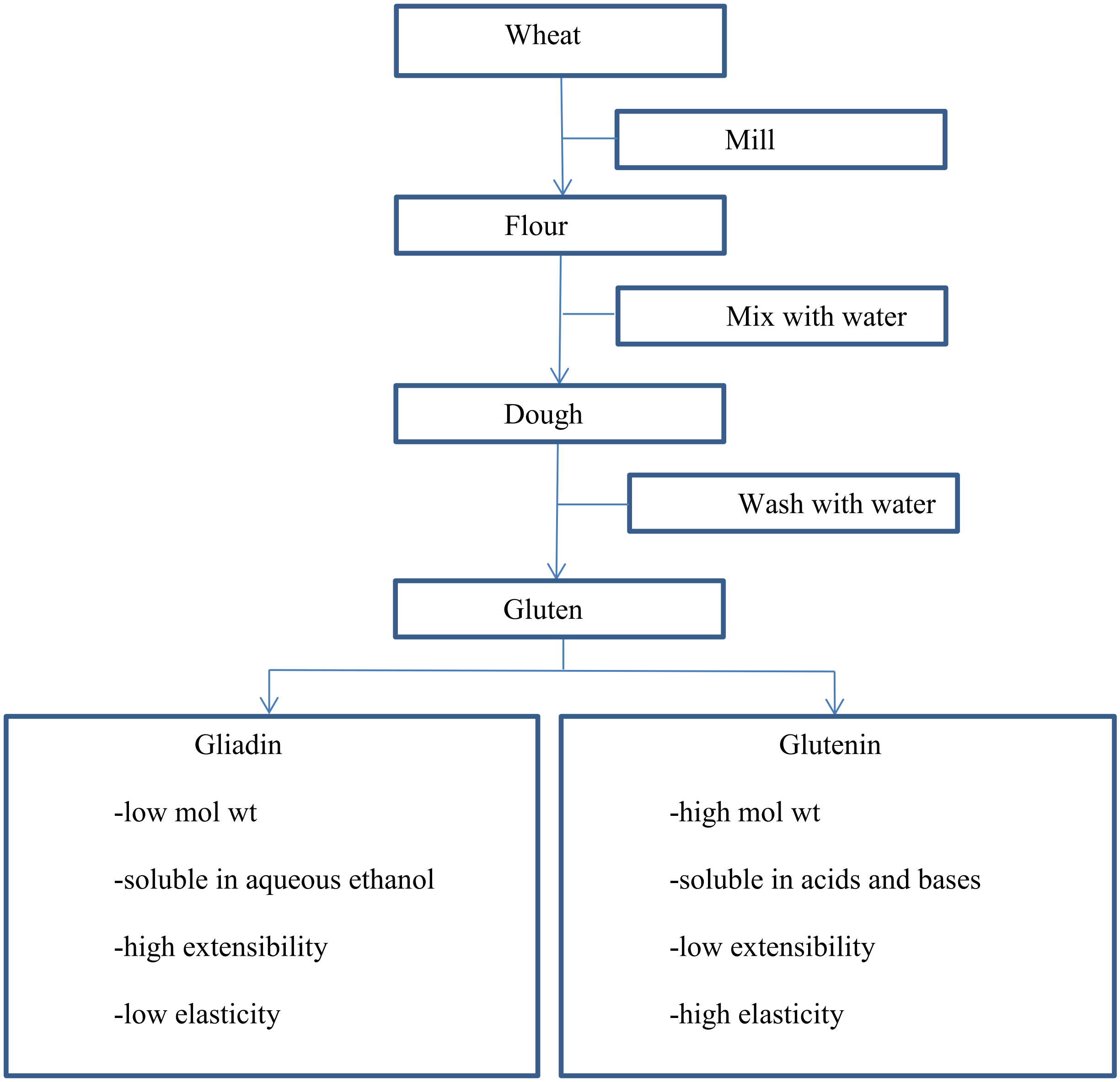

Figure 1. Schematic procedure for the preparation of gluten and its major components

Molecular properties. Gluten proteins are the major storage proteins in cereal grains and are stored in the starchy endosperm to provide amino acids for seed germination. Gluten proteins are synthesized on the rough endoplasmic reticulum and then directed into the lumen of the plant cell via a standard signal peptide-mediated mechanism (Shewry et al., 1995). They are then deposited in protein bodies which may be derived from direct accumulation within the endoplasmic reticulum lumen or transport via the Golgi apparatus to the vacuole (Shewry et al., 1995). The protein bodies' diameter ranges up to about 20 μm but as the endosperm cells fill with starch the protein bodies become disrupted and coalesce to form a matrix of storage proteins surrounding the starch granules in the mature dry tissue (Shewry et al., 1995). It is this matrix that forms a continuous network called gluten when the endosperm is milled and the flour mixed with water and kneaded.

Gluten is made up of two proteins, glutenin and gliadin (Figure 1), as described below.

Gliadin. Gliadin is the portion of the gluten proteins that is 70% soluble in aqueous ethanol and comprises of 35-40% of wheat flour proteins (Figure 1) (Khan & Bushuk 1979). Gliadin imparts the viscous component to the viscoelastic properties of gluten. In human physiology, gliadin, on ingestion, initiates the autoimmune response in Celiac disease (Mendoza 2005).

Gliadin contains approximately fifty components as identified by a two-dimensional electrofocusing-electrophoresis technique (Khan & Bushuk, 1979). The molecular weights of these components are identified by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) and they range from approximately 12,000 to 80,000 daltons, with majority of the components having a molecular weight of approximately 36,000 daltons (Khan & Bushuk, 1979).

Most gliadin components contain single chains containing intra-polypeptide disulfide bonds. The disulfide bonds are mainly due to total amino acid residues containing approximately 35% glutamic acid (Table 1) (Khan & Bushuk, 1979). Gliadin also contains about 15% proline in relation to the total amino acid residues (Table 1).

Table 1

Amino Acid Composition of Wheat Flour Components per 100,000g of Wheat Flour

Amino Acid	Gliadin	Glutenin	Gluten	Flour
Lysine	5	12.5	9	16
Histidine	14.5	13	15	19
Arginine	15	20	20	29
Aspartic acid	20	23	22	33
Threonine	18	26	21	22
Serine	38	50	40	42
Glutamic acid	317	278	290	318
Proline	148	114	137	107
Glycine	25	78	47	27
Alanine	25	34	30	25
Cysteine	10	10	14	18
Valine	43	41	45	37
Methionine	12	12	12	13
Isoleucine	37	28	33	33
Leucine	62	57	59	58
Tyrosine	16	25	20	24
Phenylalanine	38	27	32	44
Tryptophan	5	8	6	7
Amide	301	240	298	230

(Khan & Bushuk, 1979)

Proline disrupts the regular secondary structure of a polypeptide chain due to its ability to create bends wherever it occurs in the polypeptide chain. Also, gliadin contains low levels of basic amino acids and low levels of free carbonyl groups, a property that makes gliadin among the least charged proteins (Table 1) (Khan & Bushuk, 1979). Contrary to expectations of a structure that is quite different (disrupted structure due to proline) from globular proteins relative to its unique amino acids composition, gliadin proteins contain compact tertiary structures similar to those of globular proteins.

Glutenin. Glutenin is that fraction of the gluten protein that is insoluble in 70% aqueous ethanol but soluble in dilute acid and alkali (Figure 1) (Weiser, 2007). Glutenin comprises about 35-45% of wheat endosperm protein (Khan & Bushuk, 1979). They impart the elastic component to the viscoelastic property of gluten. It is mainly glutenin that undergoes extensive changes during dough mixing and the development of optimum rheological properties for maximization of bread-making potential of a specific flour (Khan & Bushuk, 1979; Tatham et al., 1990a; Shewry, 1995).

The functional behavior of glutenin in bread making is dependent on its physical (molecular shape and size) and chemical (amino acid composition, sequence and tendency to aggregate) properties. Using SDS-PAGE on reduced glutenin shows that hexaploid wheats (bread wheats) contain about 17 polypeptide subunits ranging in molecular weight from 12,000 to 134,000 daltons (Khan & Bushuk, 1979). These polypeptide units are joined to one another by interpolypeptide disulfide bonds to form long concatenated structures or joined by hydrophobic interactions and hydrogen bonds to form highly stable micelles. Tetraploid wheats lack three of largest subunits (90,000, 132,000 and 134,000 daltons) present in glutenin of bread wheats. These three large molecular weight glutenin subunits play a key role in the function of this protein in dough formation and stability during baking (Khan & Bushuk, 1979). Alkylated subunits of glutenin have been fractionated by gel filtration into three subunits based on molecular weights, lowest (68,000 to 12,000), largest (134,000 to 60,000) and those with same mobility (35,000 and 45,000). These three groups also play an important role in exhibiting glutenin's unique properties to influence the overall functional properties of glutenin in gluten and the resultant dough (Khan & Bushuk, 1979).

Glutenin amino acid composition (Table 1) reflects a high glutamic acid content that is all present as glutamine. This provides numerous amides groups that can form intra and inter-molecular hydrogen bonds; a very important rheological feature in hydrated gluten (Khan & Bushuk, 1979). Glutenin contains a high proportion of hydrophobic amino acids such as leucine which interact with each other at the non-polar side of the chain in aqueous environments as in dough to form hydrophobic bonds. In lager numbers, these weak bonds help in stabilizing glutenin aggregates. Glutenin is insoluble in aqueous solvent due to having less amino acids with acidic and basic side groups (Khan & Bushuk, 1979).

Glutenin appears as asymmetrical molecule with a low α helix content (10-15). It contains more α helix structure in hydrochloric acid, less in urea solutions (Khan & Bushuk, 1979) and the amount of α helix structure is also influenced by changes in the ionic strength. Secondary, tertiary and quaternary structures of glutenin can be modified by oxidizing agents, reducing agents and mechanical development to produce bread of optimum loaf volume and crumb structure (Khan & Bushuk, 1979).

Functionality in Food

Functionality in cereal products. Wheat flour is the major ingredient in almost all breads, pizza crust, rolls, chapaties, crackers, cookies, biscuits, cakes, doughnuts, muffins, pancakes, waffles, noodles, macaroni, and spaghetti (Inglett, 1977; Belton et al., 1995; Schober, et al., 2008; Sivam et al., 2010). In baking process of these wheat-based products, gluten proteins require adequate hydration and shear to promote protein cross-linkages between glutenin and gliadin (Figure 2) (Shewry et al., 2001; Juliano, 1985). This is desired so as to form an interconnected protein film capable of trapping expanding gas bubbles in the dough to provide leavening in baked goods (Figure 3) (Huebner & Wall, 1976; Inglett, 1977; Landillon et al., 2008; Letang et al., 1999). Shear/kneading is required to break down disulfide bonds between adjacent chains and realign them to form a continuous protein sheet (Stauffer, 1998). Other grains and starches lack the mechanism promoting gas retention, flexibility, and enhanced water retention (Wieser & Koehler, 2008).

Gluten matrix is a major determinant of the important properties of dough (extensibility, resistance to stretch, mixing tolerance, gas holding ability). In a dough network, gluten encloses the starch granules and fiber fragments (Figure 3) (Gan et al., 1995; Gallagher et al., 2004). It is important that gluten should have a precise balance between elasticity and extensibility because excessive elasticity would limit expansion during gas retention and insufficient elasticity would fail to retain carbon dioxide/gas (Shewry et al., 1995). Gluten elasticity is often referred to as dough strength, and strong doughs are required for products such as bread, pasta, noodles, chapati, and pizza. In contrast weaker (less elastic) doughs are required for making cakes and cookies (Shewry et al., 1995).

Absence of gluten often results in a liquid batter rather than a dough, and can result in baked bread with a crumbling texture, poor color and other quality defects after baking (Huebner & Wall, 1976; Payne et al., 1979). Rotsch (1954) concluded from his findings that bread doughs without gluten can only retain gas if another gel replaces the gluten.

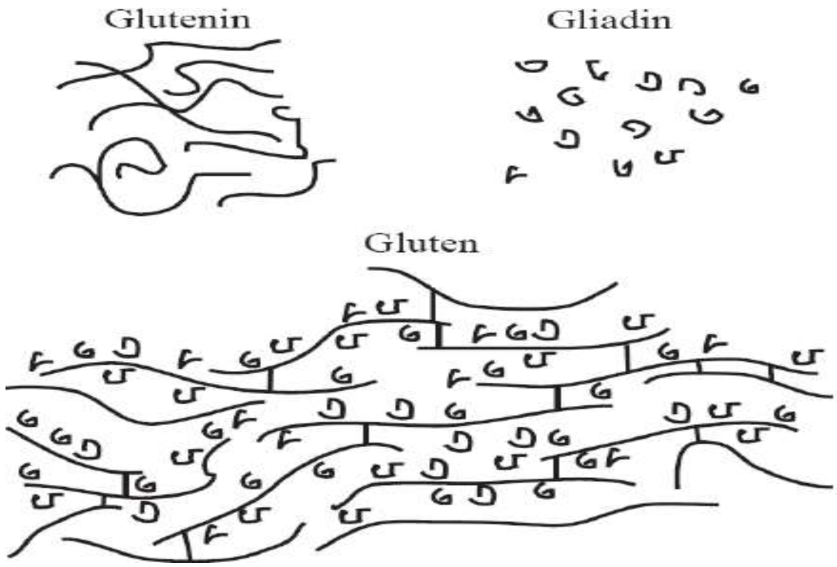

Figure 2. Schematic drawing of gliadin and glutenin association and disulfide linkages that form gluten (Crockett 2009)

Preparation of gluten-free flat breads and pasta is difficult, as the gluten contributes to a strong protein network that prevents dissolution of the pasta during cooking or breaking of pizza crust dough during sheeting. The diversification of gluten-free raw materials sometimes necessitates modifications to the traditional production process (Marconi & Careca, 2001). Such problems are rarely encountered during the manufacture of gluten-free cookies, as the development of a gluten network in cookie dough is minimal and undesirable; the texture of baked cookies is primarily attributable to starch gelatinization and sugar rather than a protein/starch structure (Gallagher, 2002).

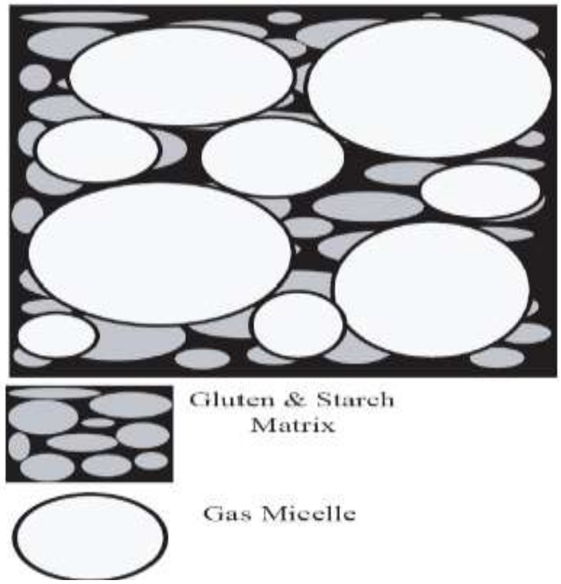

Figure 3. Schematic representation of wheat dough foam (Gan et al., 1995)

Many different products are made from gluten proteins which demonstrate the versatility of these proteins. Therefore, better understanding of the structure of these proteins would lead to taking further advantage of enormous industrial potential these proteins possess (Khan & Bushuk, 1979).

Functionality in pizza dough. Pizza industry growth has been with unprecedented momentum in recent decades (Sun & Brosnan, 2003), and the increase in demand has made companies show increased interest in the industrial production of pizza dough (Arendt & Bello, 2008). There are two types of pizza; deep pan and thin and crispy pizza. Deep pan pizza needs high protein wheat flour, and is fermented with yeast to produce a bread-like base. Thin and crispy pizza uses lower protein wheat flour than deep pan and can be fermented or gas aerated to produce a biscuit-type base (Gallagher, 2008). Pizza dough preparation process is straight forward (Figure 4). There are varied ingredients used along with wheat flour. They are salt, water, and baker's yeast as a leavening agent. Different types of lactic acid bacteria and yeast are reported to be involved in the leavening process (Coppola et al., 1998).

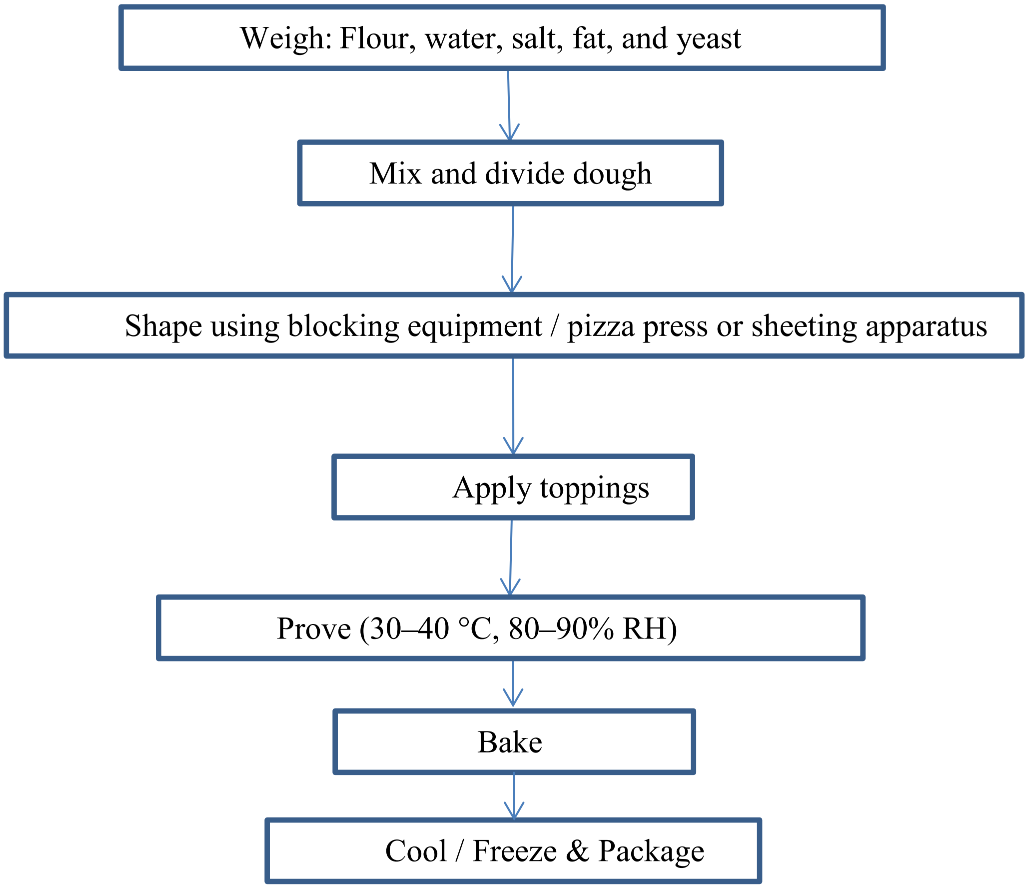

Figure 4. Schematic representation of pizza production (Gallagher, 2008)

The overall quality of a pizza depends mainly on the gluten dough, whose properties are affected by the leavening process, in addition to the flour type and preparation procedure. For a good-quality pizza, the dough has to be sheetable, to rise on proving, hold the gas produced by the yeast, as well as to have good textural and sensory attributes (Gallagher, 2008). Larsen et al. (1993) reported that pizza crust's appearance, taste and texture are important factors for consumer identification and acceptance. As for bread, hard wheat flour is the principal ingredient of pizza crust (Gallagher, 2008). Hard wheat flour yield strong gluten dough with high elasticity.

The quality of gluten present in the flour must yield balance between elasticity and extension such that once the flour is hydrated, a cohesive, extensible dough is formed, and as mentioned earlier should be able to rise during proofing and retain its shape during the sheeting process.

Comparing pizza with other baked products, pizza quality, and in particular gluten-free pizza crust quality remains a less researched area (Arendt & Bello, 2008).

Food Sensitivity Associated with Gluten

Food sensitivities and allergy. Consumption of certain foods may result to death due to related sensitivities and food allergies. In the United States, approximately 30,000 people require emergency care and 150 people die each year due to food sensitivities; around 2% of adults and 5% of children suffer from food allergies (U.S. Food and Drug Administration, 2004). Health-care and other economic costs due to food sensitivities are estimated to be approximately $7 billion per year (Asthma and Allergy Foundation of America).

Food sensitivity and allergy are individualistic adverse reactions to foods; most people eat the same food without ill effects (Taylor, 1987). As illustrated in Figure 5, these adverse reactions can be categorized as immunological sensitivities, non-immunological food intolerances and secondary sensitivities.

A true food allergy is a heightened reaction of the immune system to components of certain foods that are otherwise harmless to most people (Asthma and Allergy Foundation of America). The food components that educe these abnormal immune responses are typically naturally-occurring proteins in foods. According to Lemke and Taylor (1984), true food allergies are categorized into immediate hypersensitivity reactions and delayed hypersensitivity reactions (Figure 5). Immediate hypersensitivity reactions are due to abnormal response of the immune system with the allergen-specific Immunoglobulin E (IgE) antibodies (Mekori, 1996). Whereas, delayed hypersensitivity reactions are caused by abnormal response of the cellular immune system with the sensitized T cells (Lemke & Taylor, 1994). Celiac disease is a form of delayed hypersensitivity reaction which involves abnormal immunological response to wheat and related cereals (Ferguson, 1997).

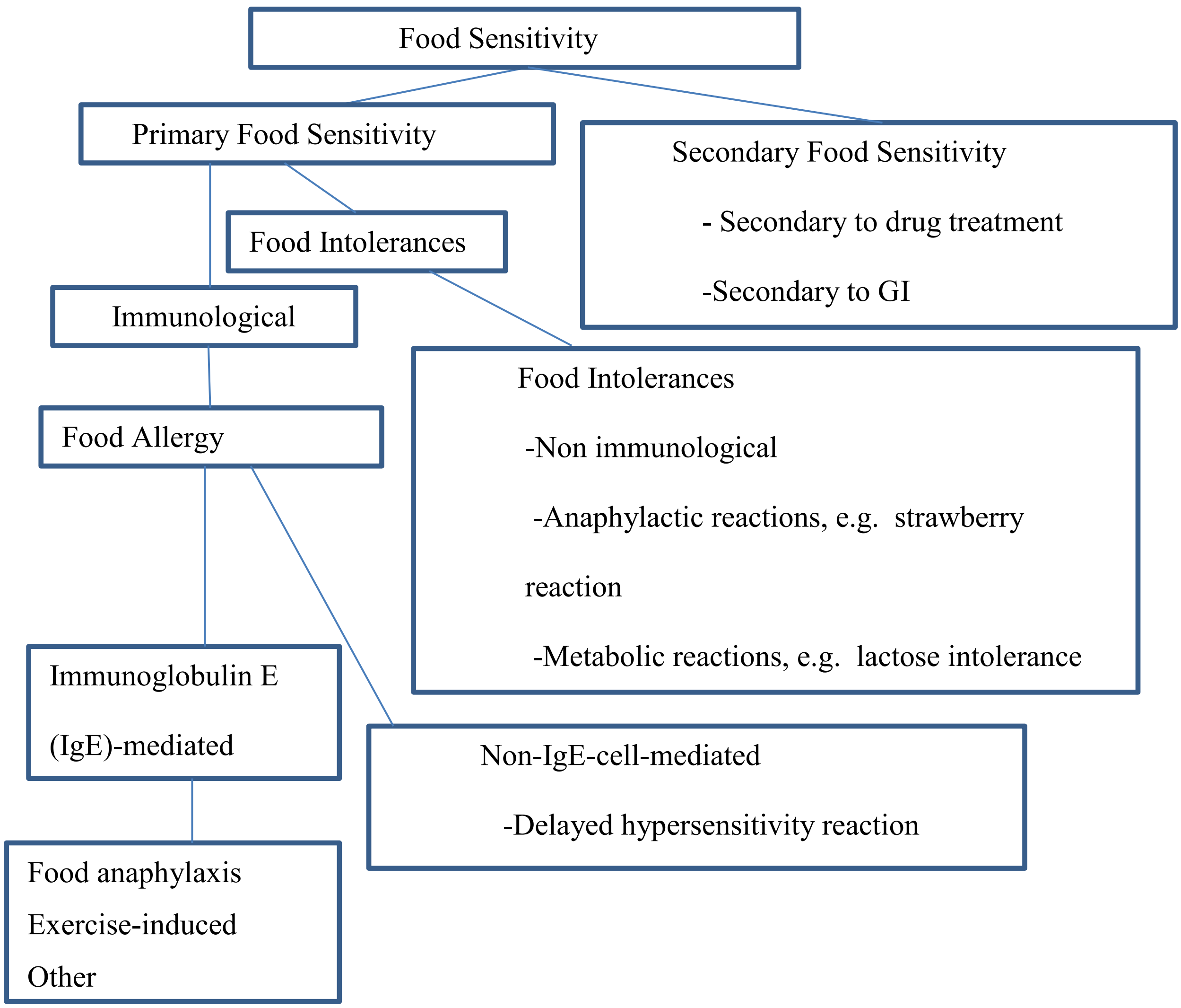

Figure 5. Schematic representation of relationships among various types of food sensitivities (Taylor & Hefle 2001)

Food intolerances do not involve immune system. Food intolerances are metabolic food disorders, anaphylactic reactions which are rapidly progressing and life-threatening allergic reaction and idiosyncratic reactions which are drug reactions that are rare and unpredictable

(Figure 5) (Taylor, 1987). Kocian (1988) reported lactose intolerance as a metabolic food disorder.

Secondary sensitivities include adverse reactions that may occur with or after the effects of other conditions (Taylor & Hefle, 2001). According to Metcalfe (1984a), lactose intolerance can be secondary to gastrointestinal disorders such as Crohn's disease.

Non-IgE-mediated food allergies are disorders mediated by T cells (Sampson, 2000). Symptoms of these disorders start to appear 24 hours or longer after the ingestion of specific foods and reach a peak at 48 hours (Lemke & Taylor, 1994). The reaction eventually subsides over 72-96 hours (Taylor & Hefle, 2001). According to Strober (1986), celiac disease occurs through a T cell-mediated mechanism.

Celiac disease. Celiac disease is also known as celiac sprue or gluten-sensitive enteropathy (Taylor & Hefle, 2001; Collin et al., 2002). Celiac disease is an inflammatory disorder of the upper small intestine triggered by the ingestion of wheat, rye, barley, oat and other products (Wieser & Koehler, 2008). Celiac disease is clinically characterized by a flat intestinal mucosa with the absence of normal villi, resulting in a generalized malabsorption of nutrients (Figure 6) (Collin et al., 2002; Davidson & Bridges, 1987; Raymond et al., 2006).

Ingestion of gluten containing foods induces an immune response which includes binding of gluten peptides to human leukocyte antigens of presenting cells and the subsequent stimulation of T-cells accompanied by the release of proinflammatory cytokines such as interferon-γ and the activation of matrix metalloproteinases. This eventually results in mucosal destruction and epithelial apoptosis (Wieser & Koehler, 2008). The intestinal mucosal lesion recovers with a gluten-free diet and deteriorates further if the patient resumes a gluten-containing diet (Trier, 1991).

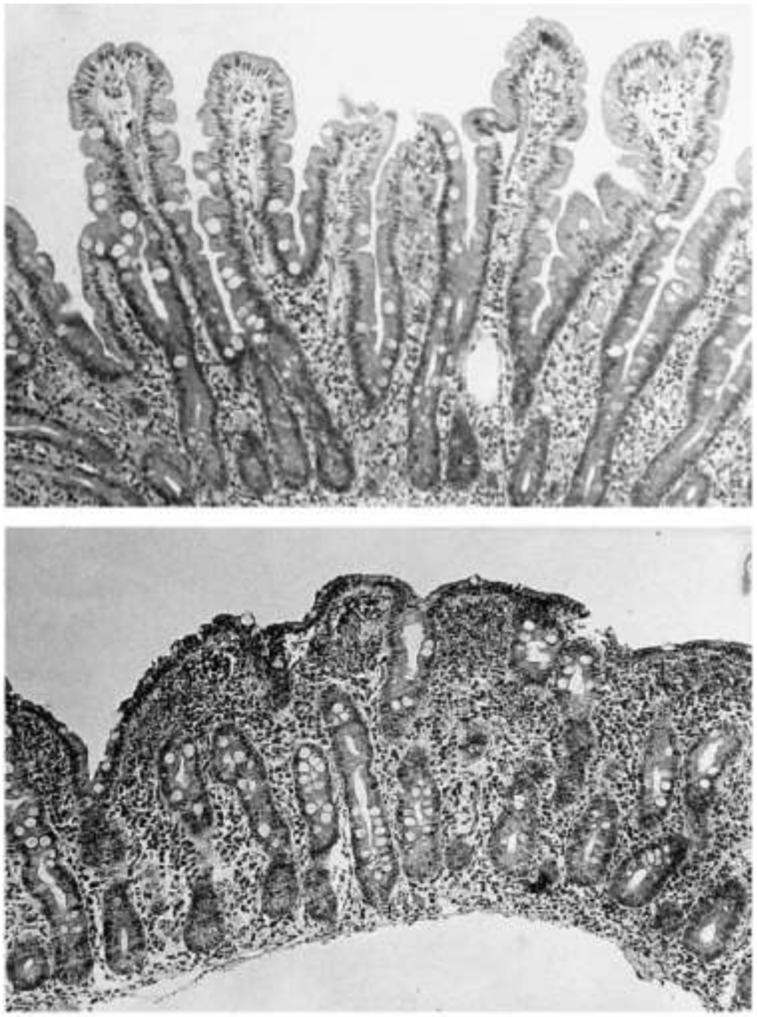

Figure 6. Top**,** normal small-bowel biopsy with finger-like villi. Bottom, small-bowel biopsy from a patient with celiac disease showing villous atrophy and hypertrophy of crypts (Collin et al., 2002)

Celiac disease affects at least 3 million people in the United States, with 97% of the celiac disease population currently remaining undiagnosed (University of Chicago Celiac Disease Center, 2011). Prevalence of celiac disease among Caucasians is now thought to be in a range of 1:100–300.

Celiac disease is not only frequent in developed countries, it is increasingly found in developing world, such as North of Sahara (Bdioui et al., 2006), Middle East (Shahbazkhani et al., 2003), and India (Sood et al., 2006). This disorder contributes substantially to childhood morbidity and mortality in many developing countries (Arendt & Bello, 2008). The highest celiac disease prevalence in the world has been described in the Saharawi, an African Arab-Berber origin (Catassi et al., 1999).

The prevalence of celiac disease is efficiently conceptualised by the iceberg model (Figure 7) (Fasano & Catassi, 2001; Arendt & Bello, 2008). The tip of the iceberg represents individuals with clinically recognized celiac disease. The majority of individuals are made up of those with undiagnosed cases or those that will develop the sensitivity in later life. Diagnoses occur at any age and symptoms vary from mild to extremely severe (Arendt & Bello, 2008).

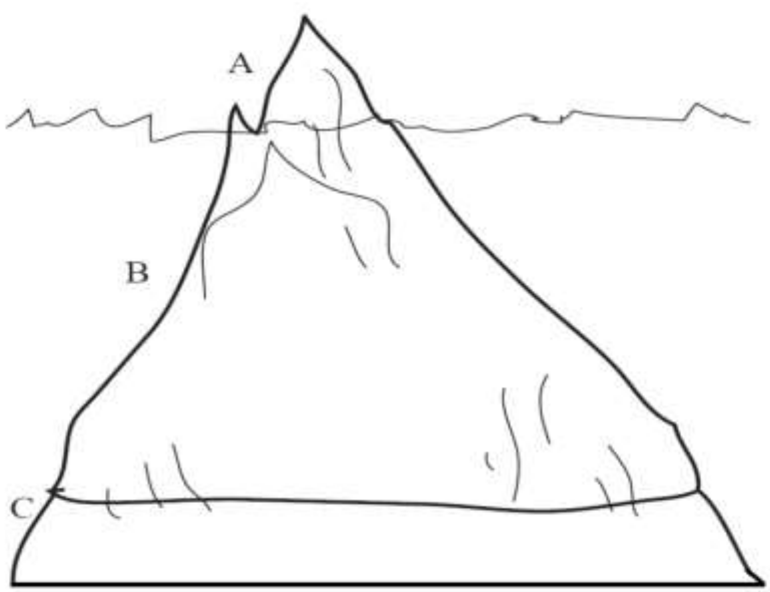

Figure 7. Iceberg model: Area **A** represents the percentage of patients with clinically diagnosed celiac disease. Area **B** represents the percentage of patients with undiagnosed or silent celiac disease. Area **C** represents the percentage of patients with a potential to develop celiac disease.

Susceptibility to celiac disease is significantly determined by genetic factors. Liability to the disease runs in families, and concordance for celiac disease in first-degree relatives ranges between 10–15% and reaches up to 80% in monozygotic twins (Collin et al., 2002). The genetic association is with human leukocyte antigens (HLA-) DQ2 and DQ8 and currently unknown non-HLA genes (Wieser & Koehler, 2008).

Celiac disease symptoms include weight loss, diarrhea, ataxia, steatorrhea, anemia, lethargy and constipation (Mendoza, 2005). In some cases, individuals do not know they suffer from celiac disease until they are diagnosed and notice a slight improvement with dietary modifications (Mendoza, 2005). The only form of treatment is a strict life-long adherence to a gluten-free lifestyle (Mendoza, 2005; Raymond et al., 2006). This requirement eliminates the choice of many wheat-based products, including the traditional pizza and wheat bread, and thereby severely restricts food choice.

Gluten-Free

Consumer demand and economic potential. There are a wide range of gluten free products in the market. They include pizza, pasta, bagels, cake mixes, waffles, even beer and gum. The increased national demand for gluten-free products is fueling a robust market for foods and drinks made without gluten (New York Daily News, 2010). This increase in demand of gluten-free products has been largely due to improved diagnostic procedures of celiac disease and changes in eating habits (Gallagher, 2009; Medeiros et al., 2011). In addition, Catassi et al. (2010) reports that the increase of gluten-product demand is due to a trend towards a loss of immunological tolerance to celiac disease throughout adulthood.

Historically, consumers have looked to natural foods retailers or the internet for these gluten-free food options. However, with the growth of demand for gluten-free foods, conventional markets account for 63% of gluten free products purchased (Gallagher, 2009). For example, in 2006, the number of gluten-free products increased to over 2,400 in natural supermarkets/food stores and to over 1,400 in conventional supermarkets/food stores (Rourke & Tirone, 2007).

Sales of gluten-free products increased 74 percent from 2004 to 2009 and were projected to grow from 15 to 25 percent a year by 2013 (Kuntz, 2006). Reporting on food trends, Sloan (2011) highlighted that sales of gluten-free products reached 2.9 billion dollars in 2010. This has been a rapid rise in sales of gluten-free products growing from a modest $210 million in 2001 (Kuntz, 2006).

In 2009, sales of products such as wheat-free breads and cakes had already enjoyed sales growth of over 120% in the last three years alone (Gallagher, 2009). This reached $65 million with the most interest in snack foods and bakery items (Table 2).

Table 2

New Products Claiming 'Gluten-Free' in the United States by Year

Year	Number of new food and beverage products
2004	202
2005	232
2006	610
2007	636

(Gallagher, 2009)

Medeiros et al. (2011) reported that although gluten-free products are viewed as a niche market, recognizing the possibility that this niche may be larger than expected and may continue to grow is important. With the estimate that 10% of the general population is being affected by some type of wheat product or protein, then potential to serve this segment of the population with gluten free food is no longer relegated to niche market (Medeiros et al., 2011).

Gluten-free pizza crust. Commercially available gluten-free pizza crusts exist (Gallagher, 2008). These are based on ingredients such as wheat starch, maize starch, potato starch, cassava starch, sorghum flour, rice flour, corn flour, gums, and emulsifiers. However, the topic still remains a little-researched area (Arendt & Bello, 2008).

O'Brien et al (2002) reported on gluten-free pizza crust research at University College Cork, Ireland based on formulation, rheological aspects and baking properties. In this research, combining a variety of gluten-free flours and starches, protein sources (egg, soy), or hydrocolloids (guar gum) and a microencapsulated high-fat powder, it was possible to fulfill consumer acceptance and requirements based on appearance, taste and texture (Gallagher, 2008). Tests such as dough hardness, texture (pizza crust hardness), color, and pizza volume confirmed that it is possible to produce a gluten-free pizza product with similar attributes to the wheat-based control.

Hydrocolloids

Hydrocolloids are diverse range of biopolymers (e.g. proteins and polysaccharides) derived from natural sources (e.g. plants, animals, seaweed or microbial origin) that form a gel with water (Rosell et al., 2007; Gallagher, 2009). Hydrocolloids are commonly named as gums, are capable of controlling both the rheology and texture of aqueous systems through the stabilization of emulsions, suspensions and foams (Diezak, 1991; Gallagher, 2009). Also, they are used to slow down retrodegradation, increase moisture retention and increase overall quality of products during storage time (Rojas et al., 1999). Based on their functionality in food systems, they could be classified in three main categories: thickeners, gelling agents and emulsifiers (Table 3).

Structural properties of hydrocolloids and their influences by processing variables (e.g. heat, pH and shearing) determine their functionality (Gallagher, 2009). The structure-functional relationships of hydrocolloids and their roles in foods have been extensively investigated (Funami et al., 2005b; Casier et al., 1977; Lazaridou et al., 2007).

Various investigations on the effect of supplementing gluten-free doughs with hydrocolloids on standard farinograph curves have been conducted (Gujral et al., 2003a; Sivaramakrishnan et al., 2004; Lazaridou et al., 2007). In these studies, Lazaridou et al. (2007) reported that water absorption of gluten-free doughs based on rice flour, corn starch and milk proteins increased following the addition of various hydrocolloids, such as pectin, agarose, CMC and xanthan gum due to the hydrophilic nature of these biopolymers. They found out that the water absorption of formulations containing hydrocolloids at 2% level (rice flour basis) varied in range 63.4% - 67%. Also, the dough development time farinograph parameter increased with the addition of hydrocolloids from 4 minutes for the control to the range of 7.5-26.5 minutes, with exception of xanthan, which decreased the dough development time to 2 minutes. The dough elasticity and cohesiveness when 500BU of consistency is reached, was differently affected by each hydrocolloid with xanthan gum resulting to the highest elasticity values (100BU). Xanthan gum farinograph curve resembled that of a standard farinograph curve typically obtained by wheat flour (Gallagher, 2009).

Table 3

Common Hydrocolloids and Their Functionality in Food Products

Source	Hydrocolloid	Functionality
Plant	pectin	Gelling, thickening
	B-Glucan	Gelling
	Gum Arabic	Thickening
	Guar gum	Thickening
	Locust bean gum	Thickening
	Arabinoxylan	Gelling
Seaweed	Agar	Gelling
	Alginate	Gelling, thickening
	Carrageenan	Gelling
Animal	Milk proteins	Gelling, emulsification
	Egg proteins	Gelling, emulsification
	Gelatin	Gelling, emulsification
Microbial	Xanthan gum	Thickening

(Gallagher, 2009)

Gallagher (2009) reports that fundamental rheometry conducted on gluten-free doughs revealed an improvement in the viscoelastic properties of gluten-free doughs after supplementing the formulations with hydrocolloids. Addition of various hydrocolloids at 1% and 2% levels (rice flour basis) resulted in rise of elastic modulus, *G'* as well as an increase in the resistance to deformation (Lazaridou et al., 2007). Xanthan gum, β-glucan and pectin addition resulted to firmer doughs (higher *G*' values) with increasing hydrocolloid concentration. The firming of the dough indicated that the rise of the biopolymer level affected the rheological properties more than the increasing content of water (Gallagher, 2009).

Lazaridou et al. (2007) found that the elasticity and resistance to deformation of doughs followed the order of xanthan >CMC>pectin>agarose> oat β-glucan. The elasticity of the gluten-free doughs depended on water and hydrocolloid and increased by 65-75%, 45-50%, 35-40%, 25% and 8-15% when xanthan, pectin, agarose and oat β-glucan, respectively, were added. Apart from the concentration effect, the magnitude of influence of hydrocolloids on rheological properties of gluten-free doughs seems to be related to the molecular structure and chain conformation of the polysaccharide that determine the physical intermolecular associations of the polymeric chain (Gallagher, 2009). The highest elasticity of dough formulations supplemented by xanthan gum could be explained by the weak gel properties and high viscosity values at low shear rates of aqueous xanthan gum dispersions due to its rigid, ordered chain conformation (Doublier & Cuvelier, 1996; Rodd et al., 2000; Gallagher, 2009).

Xanthan Gum

Properties. Xanthan gum is produced by aerobic fermentation of a pure culture of the bacterium *Xanthomonas campestris* (Borges & Vendruscolo, 2007; Ben Salah et al*.,* 2009). It is an anionic polysaccharide which possesses a cellulosic backbone of (1,4)-b-D-glucose residues, and a trisaccharide side chain consisting of b-D-mannose-(1,4)-b-D-glucuronic acid-(1,2)-b-D mannose attached at C-3 to alternate glucose residues of the main chain (Figure 8) (Garcia-Ochoa et al*.,* 2000; Rosalan & England, 2006; Ben Salah et al., 2009). Xanthan from different suppliers are very similar. They are made up of rigid helix rods and xanthan polymers can pack closely to each other forming strong gels with a high yield stress point (Whitecomb & Macosko, 1978). Once the stress applied overcomes the yield stress point, xanthan shears readily (Whitecomb & Macosko, 1978).

Xanthan is a biopolymer most widely accepted commercially with application in numerous industrial segments due mainly to its rheological properties that allow the formation of viscous solutions at low concentration (0.05–2%), and a wide range of pH and temperature stability, characteristics resulting from xanthan's ramified structure and high molecular weight (Silva et al*.,* 2009; Ben Salah et al., 2009). Xanthan can be used in foods and other segments as a thickening, stabilizing and emulsifying agent and, in synergism with other gums, can act as a gelling agent (Lopez et al., 2001).

An important property when using xanthan gum as food additive in food formulation or cosmetics is the viscosity of the resultant solution, which is a function of shear rate and depends on the molecular weights and the polymer concentration (Ben Salah et al., 2009). The molecular weight of xanthan gum has been reported to be in the order of 1.5–7 10^6 Dalton (Lopez et al., 2004).

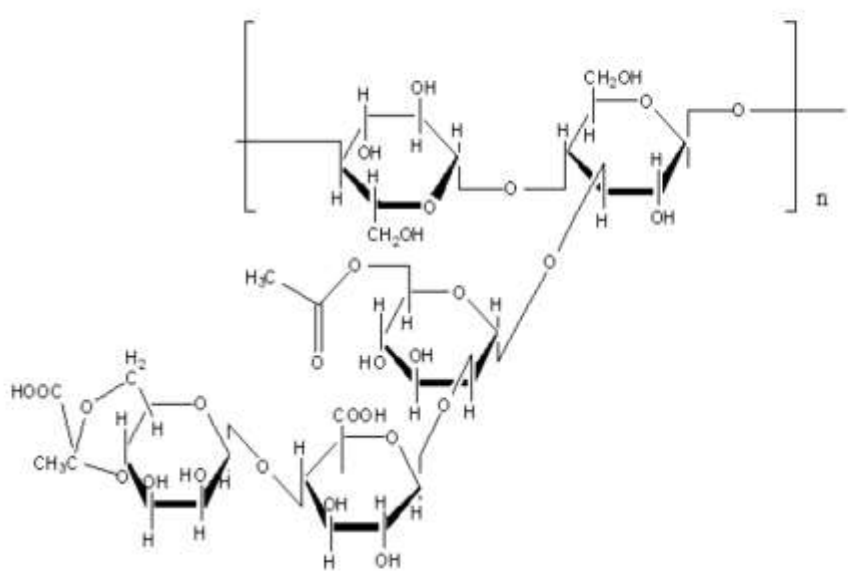

Figure 8. Xanthan gum monomer (Whitecomb & Macosko, 1978)

Functionality in food. Hydrocolloids are added to baked goods for additional water-binding to a moister softer baked good (Ahlborn et al., 2005). In gluten-free products studies they are found to improve baked bread quality by increasing gas retention, specifically increasing loaf volume in bread (Arendt & Bello, 2008; Gallagher et al., 2003a; Lee et al., 2002). All hydrocolloids are able to modify starch gelatinization (Rojas et al., 1999) and some studies have reported the use of hydrocolloids as fat replacements (Lucca & Trepper, 1994). In a study by Ahlborn et al. (2005), they determined that a blend of xanthan and HPMC improved moistness and overall freshness of rice bread over that of the control rice bread and wheat bread.

Xanthan gum forms high-viscosity pseudoplastic material and is very common in commercial gluten free products (e.g., loaves). This behavior of xanthan gum is important in bakery products during dough preparation, i.e., pumping, kneading and rolling (Lorenzo et al., 2008). Xanthan is never used alone but in combination with alternative proteins, hydrocolloids, or even supplemented with amino acids (Ahlborn et al., 2005; Lazaridou et al., 2007; Gambuś et al., 2007). Also as mentioned earlier in xanthan gum properties section, it can be used in foods and other segments as a thickening, stabilizing and emulsifying agent and, in synergism with other gums, can act as a gelling agent (Lopez et al., 2001).

Functionality in cereal dough including pizza crust. Rotsch (1954) demonstrated the potential of substances that swell in water to mimic the gluten properties in dough. Kulp et al. (1974) reported the incorporation of xanthan gum in the production of a pure wheat-starch bread. Since then, the use of hydrocolloids in gluten-free products has been increasing (Table 4).

Table 4

Summary of Studies Involving Gluten-Free Breads and Xanthan Gum

Bread main ingredients	Hydrocolloids	Reference
Wheat starch	Xanthan gum	Kulp et al. (1974)
Rice flour	HPMC, locust bean gum, guar gum, carageenan, xanthan gum	Kang et al. (1997)
Rice flour, corn starch, cassava starch	Xanthan gum	Lopez et al. (2004)
Rice flour, dairy-based proteins	Xanthan gum, konjac gum	Moore et al. (2004)
Rice flour, milk proteins, egg proteins	Xanthan gum, HPMC	Ahlborn et al.(2005)
Sorghum	Xanthan	Schober et al. (2005)
Rice flour, potato starch, corn flour	Xanthan gum	Moore et al. (2006)
Rice flour, corn starch, sodium caseinate	CMC, pectin, agarose, xanthan gum, b-glucan	Lazaridou et al. (2007)

In 1976, Nishita et al. reported the development of a yeast-leavened rice bread formula using different additives. In this study, hydrocolloids provided the dough with the viscosity necessary to trap fermentation gases, and the 'water-release' effect necessary for starch gelatinization during baking.

When xanthan, guar gum, locust bean gum and tragant were added as binding agents and gluten substitutes in bread made from corn starch (Acs et al., 1997), these agents efficiently substituted the technological effect of gluten in gluten-free systems, resulting in a highly significant increase in bread volume and loosening of the crumb. Individually, evaluation of the effect of the gums showed that the highest quality bread was the one containing xanthan.

The textural comparisons of gluten-free and wheat-based doughs, batters and breads containing xanthan gum (1.25%) or xanthan (0.9%) plus konjac gum (1.5%) have been performed (Moore et al., 2004; Anton & Artfield, 2008). Regardless of the addition of hydrocolloids, all gluten-free breads were brittle after two days of storage, detectable by the occurrence of fracture, and the decrease in springiness, cohesiveness and resilience derived from texture profile analysis.

Schober et al. (2005) did a study that tested the quality differences among sorghum hybrids in the quality parameters of gluten-free breads made from this cereal. Using xanthan gum (0.3-1.2%) and response surface methodology, they observed that increasing hydrocolloid levels would cause a decrease in the loaf specific volumes. Consequently, they attested that xanthan gum had negative effects on crumb structure of sorghum breads and that, with the addition of corn starches, their textural aspects could possibly be better improved. The microstructure analysis of gluten-free breads regarding the staling process and its correlation with sensory and mechanical properties showed beneficial effects of hydrocolloids (Ahlborn et al., 2005; Anton & Artfield, 2008). This study demonstrated that the formulation containing rice, egg and milk proteins, xanthan gum, and HPMC created a continuous matrix with starch fragments. Hence, the addition of these hydrocolloids resulted in a structure similar to gluten.

Moreover, the gluten-free rice bread had the highest sensory scores for both moistness and freshness, which was probably due to the xanthan and HPMC water-retention properties.

Dairy Ingredients in Baking

Dairy products such as dairy proteins (whey, casein) and non-fat dry milk powder have been popularly used as ingredients in the dairy industry (Stahel, 1983; Zadow & Hardham, 1981). Dairy proteins are highly functional ingredients and due to their versatility can be readily incorporated into many food products (Gallagher et al., 2004). These proteins are used in bakery products for their nutritional properties, functional benefits including flavor and texture enhancement, and better handling and storage improvements (Cocup & Sanderson, 1987; Arendt et al., 2001; Mannie & Asp, 1999). When used in gluten-free product formulas dairy proteins increase water absorption and, therefore, enhance the handling properties of the dough (Gallagher et al., 2004). However, supplementation of gluten-free breads with the high lactose-content dairy powders is not suitable for celiac disease people who have significant damage to their intestinal villi as they may be intolerant of lactose due to the absence of the lactase enzyme which is generated by the villi (Ortolani & Pastorello, 1997). When incorporated into gluten-free breads, dairy powders with high protein/low lactose content (sodium caseinate, milk protein isolate) give breads with an improved overall shape and volume, and a firmer crumb texture (Gallagher et al., 2003). The added dairy proteins give appealing dark crust and white crumb appearance to the breads, and receive good acceptability scores in sensory tests (Gallagher et al., 2003). Supplementing the gluten free formulation with high protein-content dairy powders increases protein content of these breads (Gallagher et al., 2003). When incorporated in other products (e.g. sausages) dairy proteins form gels upon heating and cooling and increase the firmness of the products (Pearson & Gillett, 1996).

Whey protein. Whey is the liquid that originates from coagulation of milk and is generated from cheese making (Onwulata & Huth, 2008). There are different types of whey: (1) sweet whey, with a pH of at least 5.6, originates from rennet coagulated cheese production such as cheddar. (2) Acid whey, with a pH not higher than 5.1, comes from acid-coagulated cheeses manufacture such as cottage cheese (Tunick, 2008). About 9 liters of whey is generated for every kilogram of cheese manufactured and a large cheese-making plant can generate over a million liters of whey daily (Jelen, 2003).

Whey protein is commercialized as liquid or powder, where whey powder is the most common in the market. The powered whey is generated from either drum drying, concentration, or isolation with the latter two forms being termed as whey protein concentrate and whey protein isolate, respectively. The mode of protein concentration and isolation is through ultra-filtration, electrodialysis, microfiltration, nanofiltration or reverse osmosis followed by spray drying (Onwulata & Huth, 2008).

Whey protein is used in many food applications because of its functionality and nutritive value. Whey protein creates and stabilizes air bubbles in a liquid and has good foaming capacity (Renner & Abdi El-Salam, 1991). Ice creams, soufflés, frothed drinks, and other food foams and emulsions are stabilized by surface active agents for which whey protein products are frequently selected (Foegeding et al., 2002). Acid whey powder improves the crust color and enhances flavor in bread, biscuits, crackers, and snack foods by providing a golden surface on baking (Kosikowski, 1979). Upon heating, whey protein unfolds and aggregate and are capable of binding large amounts of water depending on the pH, ionic strength, and thermal conditions (Hudson et al., 2000).

Whey acts as a tenderizer in those foods where a soft or tender structure is desired (Gillies, 1974). The tenderizing properties are generally noticeable in the cake-like texture of baked goods, mild brittleness of cookies and the delicate gel structure of starch pudding mixes (Gillies, 1974).

Addition of 4% whey protein concentrate increases extensibility; milk proteins cause increase in protein network while untreated whey protein concentrate appears to interfere with the gluten network when compared to the control (Kenny et al., 2001).

Non Fat Dry Milk Powder

Nonfat dry milk (NFDM) and other dairy ingredients are widely used in the preparation of bakery products. They are used to improve nutritional, organoleptic, and some functional properties of the baked product (Eedogdu-Arnoczky et al., 1996). Use of NFDM increase water absorption, reduce staling rate, and increase crust color in bread baking (Dubois & Dreese, 1984).

The complexity of the bread making system, including several stages of processing and interaction among the components, makes it difficult to predict the performance of a particular dairy product based on its behavior in a model system. The performance of a NFDM may vary with flour composition and strength, presence of additives, bread making system and tested parameter (Eedogdu-Arnoczky et al., 1996). In the NFDM studies conducted towards this dissertation, the effects of other proteins from the flours were assumed to be minimal, and that only NFDM had main effects on dough texture.

Rheological Properties of Doughs

Rheology is the study of the manner in which materials respond to strain or stress, the science of deformation and flow of matter (Mirsaeedghazi et al., 2008).

During the product development and process development of industrial manufacturing of food products, it is critical to understand the rheological characteristics of food materials, including the product of interest in this work, gluten-free pizza crust dough. Rheological studies are among the most convenient methods for measuring process performance and shelf indicators of quality of food products, including cereal doughs. Rheological characterization can describe how the doughs would respond (flow, rupture, deform) during processing (sheeting, pressing) when stress is applied. Characterization can therefore be used as a tool in the selection and specification of raw materials/ingredients and processing conditions.

Knowledge of fundamental rheological properties of any dough could indicate how the dough is going behave under various processing conditions. This knowledge is import in terms of product formulation and optimization, quality control, machining properties of the dough, scale-up of the process and automation (Bushuk, 1985; Hamann & Macdonald, 1992). Shear behavior can be a predictor of baking performance (Dobraszczyk et al., 2001). This is because bread dough undergoes rigorous stress during mixing and expansion of gases during proofing and baking. The final bread volume and crumb texture is directly correlated with dough handling ability (Dobraszczyk et al., 2001).

Dough Elongation Method

The method used in this dissertation involved an Intsron (model 3342, Instron EXTRA, Norwood, MA) machine mounted with probes that hold the dough and stretch it with a constant speed. Since dough properties change rapidly after sheeting, studying the effect of sheeting on dough properties requires rapid measurement.

Gujral and Pathak (2002) used the Instron Universal Testing Machine to determine the tensile properties of chapaties prepared from composite flours (wheat and black gram). Also, Stiffness, breaking strength and deformation of rectangular strips of chapaties were measured by a tensile test performed using an Instron by Waniska (1990). In another study, Rizley and Suter (1977) used tensile test to evaluate textural properties of tortillas made from different varieties of sorghum.

In this study, dough elongation measurements are used to determine the dough resistance to deformation, breaking strength and stiffness in various processing conditions; handling (sheeting). This because in baking the final product texture is directly correlated with dough handling ability (Dobraszczyk et al., 2001).

Dough Puncture Test

Puncture test measures the force that is required to push a probe into food. The puncture test apparatus were attached to the Instron machine where the probe penetrated the food to constant depth causing irreversible crushing. Simultaneously, the maximum force exerted to the food was measured.

Lorenzo et al. (2008) conducted a study to determine the behavior of empanadas to rupture using the puncture test. Also, puncture test has been used to determine rheological behavior of papad dough for the purpose of sheeting and rolling (Bhattacharya & Narasimha, 2007). It's the same basis that we used puncture test in this dissertation to study resistance of gluten-free pizza dough to puncture force.

Texture Profile Analysis

The rheological properties of dough in relation to its texture measurements could help understand the behavior of dough during processing. TPA has been used for the textural evaluation of a wide range of foods. It was originally developed for the General Foods Texturometer (Szczesniak, 1963; Szczesniak et al., 1963). Bourne (1968, 1974 and 1978) has demonstrated a method to evaluate texture profile parameters from the force-deformation curves obtained by the Instron - Universal Testing Machine (UTM). The food sample is compressed twice, successively, between two parallel plates and the force-time curves are plotted. Some of the textural parameters derived from these curves are defined (Bourne, 1968a) as: (1) Hardness - the peak force during the first compression cycle. (2) Cohesiveness - the ratio of the positive force area during the second compression to that during the first compression. (3) Adhesiveness - the negative force area for the first compression, representing the work necessary to pull the compressing plunger away from the sample. (4) Springiness or elasticity - the height that the food recovers during the time that elapses between the end of the first compression and the start of the second compression. (5) Gumminess - the product of hardness and cohesiveness. (6) Chewiness - the product of gumminess and springiness.

Stickiness of a food product depends on both the cohesive forces in the food and the adhesive forces between the food and with whatever it comes into contact (Sherman, 1969). By pulling two parallel plates apart at a constant rate, a measure of stickiness could be obtained (Kumar et al., 1976).

Chapter III: Methodology

Ingredients and Additives

Gluten-free pizza dough formulations were made with cassava starch/Tapioca flour (Bob's Red Mill, Milwaukie, Oregon), sorghum flour (Bob's Red Mill, Milwaukie, Oregon) and chickpea/garbanzo bean flour (Bob's Red Mill, Milwaukie, Oregon), sugar (Great Value, Bentonville, Arkansas), salt (Great Value, Bentonville, Arkansas), instant dry yeast-quick rise (Red Star, Milwaukee, Wisconsin), apple cider vinegar (Heinz, Pittsburg, Pennsylvania) and sunflower oil (Flora, Burnaby, BA, Canada) . The variable hydrocolloid added to the gluten-free dough was xanthan gum obtained from Bob's Red Mill (Milwaukie, Oregon). Other additives to the formulation were dairy ingredients: unflavored whey protein (Natural factors, Everett, Washington) and nonfat milk powder (Great Value, Bentonville, Arkansas). The control whole wheat flour was obtained from great valley organic milling (Fountain City, Wisconsin).

Dough Making Process

Solid ingredients: cassava starch, sorghum flour, and chickpea flour (ratio of 2:1:1) or wheat flour, salt, sugar and additives (added gum or dairy ingredients), formulations on Table 5 and 6, were mixed in a Hobart mixer at speed #2 for four minutes. Vinegar, sunflower oil and water (43.5% and 41.6% total solids for gluten free dough and wheat dough respectively) were added and mixed in a Hobart mixer at speed #2 for five more minutes. The dough was then rolled over a platform to give sheets of desired thickness for textural analysis.

Gluten-Free Pizza Dough Formulations

Xanthan gum addition. All gluten-free pizza dough formulations contained cassava starch, sorghum, chickpea flour, salt, sugar, sunflower oil, vinegar, and water (Table 5).

Table 5

Gluten-Free Pizza Dough and Controls Formulations With Their Symbols

Ingredient		C1 (%)	C2 (%)	E1 (%)	E2 (%)	E3 (%)	E4 (%)
Salt		0.8	0.8	0.8	0.8	0.8	0.8
Sugar		2.7	2.7	2.7	2.7	2.7	2.7
Xanthan	1%	0	0	1	0	0	0
	2%	0	0	0	2	0	0
	3%	0	0	0	0	3	0
	5%	0	0	0	0	0	5
Wheat Flour		0	86	0	0	0	0
Yeast		2	2	2	2	2	2
Cider vinegar		4	4	4	4	4	4
Sunflower oil		4.5	4.5	4.5	4.5	4.5	4.5
Tapioca		43.6	0	43	42.4	41.8	40.6
Sorghum		21.2	0	21	20.8	20.6	20.2
Chickpea		21.2	0	21	20.8	20.6	20.2
Total		100	100	100	100	100	100

There were two controls composed of (by total weight excluding water): (i) cassava starch (43.6%), sorghum flour (21.2), chickpea flour (21.2), yeast (2%), sugar (2.7%), salt (0.8%), vinegar (4%) and sunflower oil (4.5%) in 300g batches. (ii) Wheat flour (86%), yeast (2%), sugar (2.7%), salt (0.8%), vinegar (4%) and sunflower oil (4.5%) in 300g batches. Xanthan gum was added to the gluten-free dough at 1%, 2%, 3%, and 5% by total weight excluding water. The percent water added depended on the formulations, 43.5% and 41.6% (total ingredients weight) for gluten-free and wheat doughs respectively (Table 5).

Dairy ingredients (Whey, NFDM) addition. All gluten-free pizza dough formulations contained xanthan gum, cassava starch, sorghum, chickpea flour, salt, sugar, sunflower oil, vinegar, and water (table 6).

Table 6

A Summary of 2% Xanthan Gum Gluten Formulations With Their Control

Ingredient	C3 (%)	W1 (%)	W2 (%)	W3 (%)	NFDM1 (%)	NFDM2 (%)	NFDM (3%)
Whey	0	1	2	3	0	0	0
Nonfat milk powder	0	0	0	0	5	10	15
Salt	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sugar	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Xanthan gum	2	2	2	2	2	2	2
Yeast	2	2	2	2	2	2	2
Cider vinegar	4	4	4	4	4	4	4
Sunflower oil	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Tapioca	42.4	41.8	41.2	40.6	39.8	37.2	34.6
Sorghum	20.8	20.6	20.4	20.2	19.6	18.4	17.2
Chickpea	20.8	20.6	20.4	20.2	19.6	18.4	17.2
Total	100	100	100	100	100	100	100

There was one control formulation composed of (by total weight excluding water): Xanthan gum (2%), cassava starch (42.4%), sorghum flour (20.8), chickpea flour (20.8), yeast

(2%), sugar (2.7%), salt (0.8%), vinegar (4%) and sunflower oil (4.5%) in 300g batches. Dairy ingredients were added (total weight excluding water): Whey protein at 1%, 2% and 3%, and nonfat milk powder at 5%, 10% and 15% (Table 6). The water added (43.5%) was based on total ingredients.

Texture Analyses

Dough strength (elongation, puncture), and texture profile analysis (TPA) characteristics of the treatment samples were studied using an Instron texture analyzer (model 3342, Instron EXTRA, Norwood, Massachusetts) with a load cell of 500N interfaced with Bluehill 2 software (Illinois Tool Works Inc., Glenview, Illinois).

Treatments were at least triplicated with five repeated measures from each triplicate taken. Mean values of breaking force and extension at maximum load were used to conduct statistical analysis to determine dough strength differences between treatments. Mean values of TPA parameter were statistically analyzed to determine textural differences between treatments.

Elongation test. Elongation tests were performed on dog bone shaped dough specimens (42mm long, 22.5mm wide and 4.1mm thick) using a tension grip system. Crosshead speed was set at 0.5mm/s, and maximum breaking force (N) and deformation at break (extension at the moment of rupture, mm) were obtained.

Puncture tests. A 3 mm diameter cylindrical probe moving at a constant rate of 0.05mm/s was used to determine maximum breaking force (mN). Tests were performed on cylindrical samples (52mm diameter and 4.1mm thickness) from each dough treatment.

TPA. The treatments were evaluated for their TPA properties with the Instron machine. TPA assessment parameters included adhesiveness, cohesiveness, hardness, springiness, chewiness, and gumminess measured using the method of Bourne (1978). A brief explanation of each of the terms and the metrics used to perform statistical analysis is highlighted below: (1) Hardness - the peak force during the first compression cycle. (2) Cohesiveness - the ratio of the positive force area during the second compression to that during the first compression. (3) Adhesiveness - the negative force area for the first compression, representing the work necessary to pull the compressing plunger away from the sample. (4) Springiness or elasticity - the height that the food recovers during the time that elapses between the end of the first compression and the start of the second compression. (5) Gumminess - the product of hardness and cohesiveness. (6) Chewiness - the product of gumminess and springiness.

Treatment samples were cut with a cylindrical die to a uniform size of 25mm width and 9.7mm height. A round disk probe (30mm diameter) was used to exert force on each dough sample. The dough samples were tested in TPA mode consisting of two cycles with a recovery time of 10 seconds. The probe speed was 100mm/minute and the distance of the probe compression was 85% of the sample height (9.7 mm).

Statistical Analysis

Differences between treatments (elongation, puncture, TPA) for the Gum, WP, and NFDM experiments were analyzed by Analysis of variance (ANOVA) using the force (mN) measurements at point of rupture, TPA characteristics and length measurements (mm). Significant differences among treatment means were analyzed using Tukey's HSD at 95% level of significance. All statistical procedures (analysis of variance and Tukey's HSD) were computed using the SPSS 17.0 software (SPSS Inc., Chicago, Illinois).

Chapter IV: Results

Gluten-Free Pizza Dough Formulations

Xanthan gum addition.

Elongation. Results demonstrated that the addition of xanthan gum had a significant effect ($p < 0.05$) on the mean elongation force (at maximum load), maximum extension length, and stress at yield point (at break) (Table 7, Figure 9, 10, and 11 respectively).

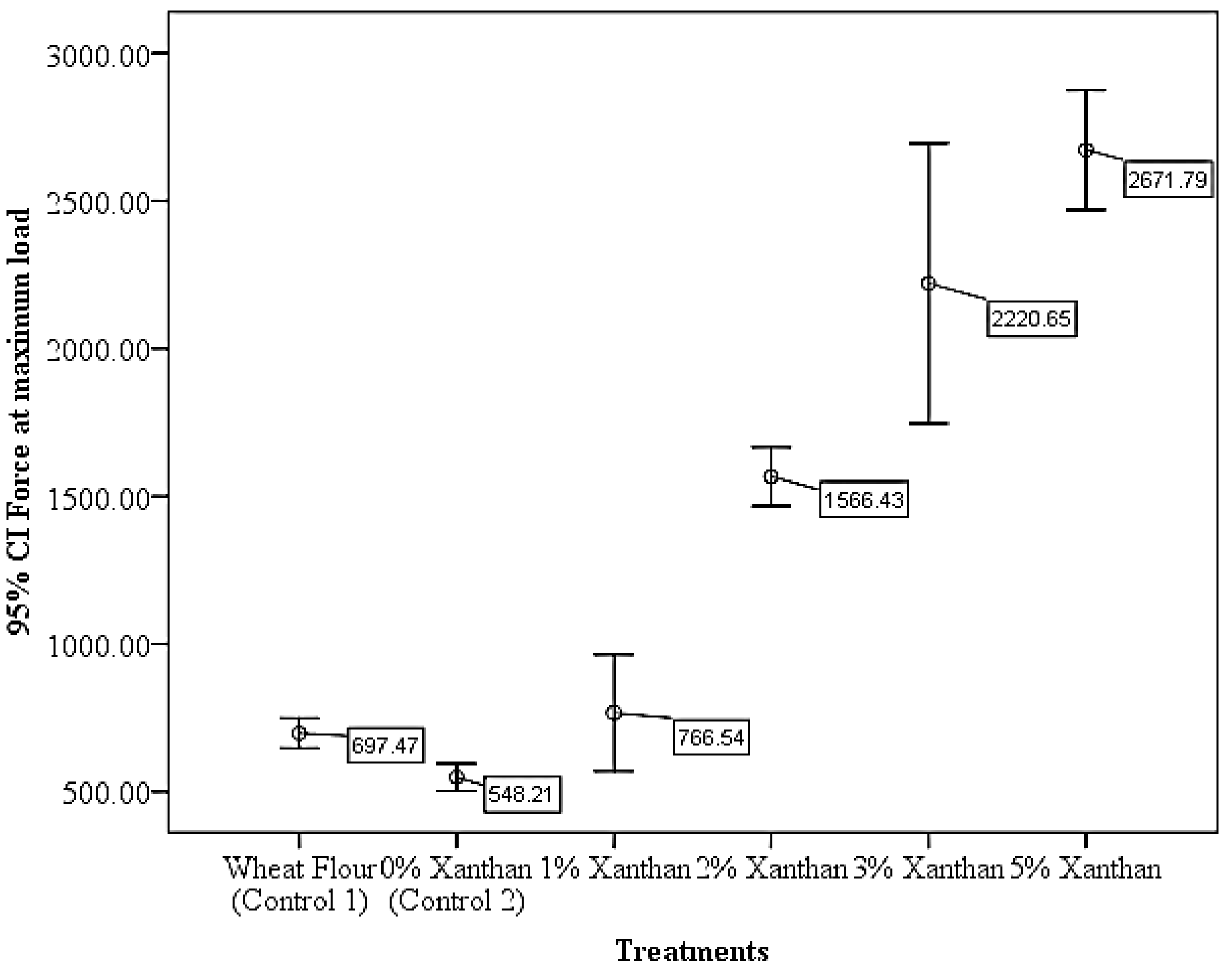

Figure 9. Effect of xanthan gum (0-5%) on the elongation force at maximum load (mN) applied on Gluten-Free dough compared to wheat flour dough

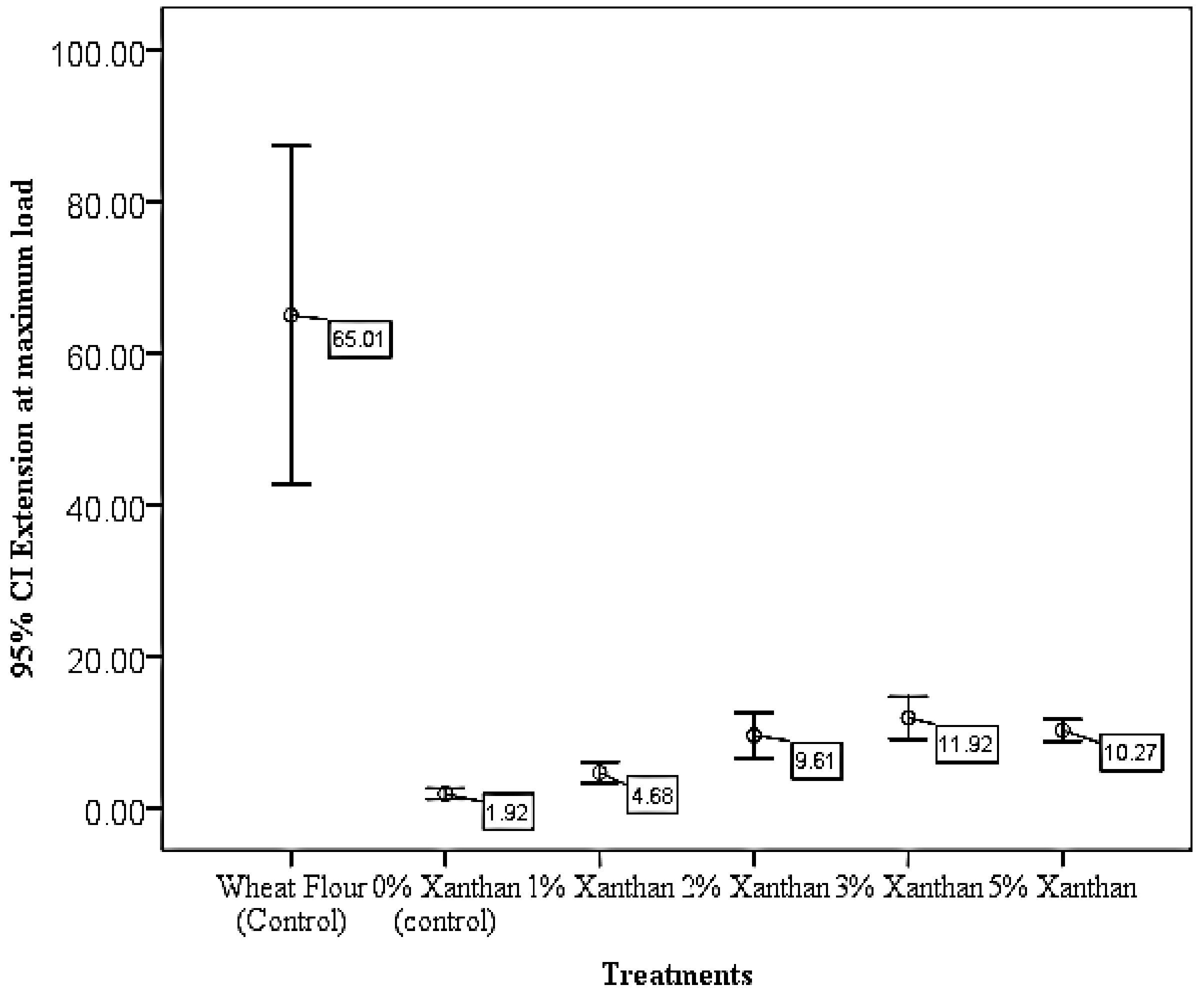

Figure 10. Effect of xanthan gum (0-5%) on the extension at maximum load (mm) of stretched Gluten-Free dough compared to wheat flour dough

Treatment means separation using Tukey's Honest Significant Difference (HSD) demonstrated that increasing levels of xanthan gum in the dough had a significant effect on increasing elongation force, extension length, and stress at yield point (Table 7, Figure 9, Figure 10, and 11). There was no significant difference in elongation force (at break point) of GF dough (0% xanthan control) and whole wheat flour dough (Table 7). When compared with wheat dough, the increase in extension length between xanthan gum treatments was not large enough to be separated by the Tukey's HSD.

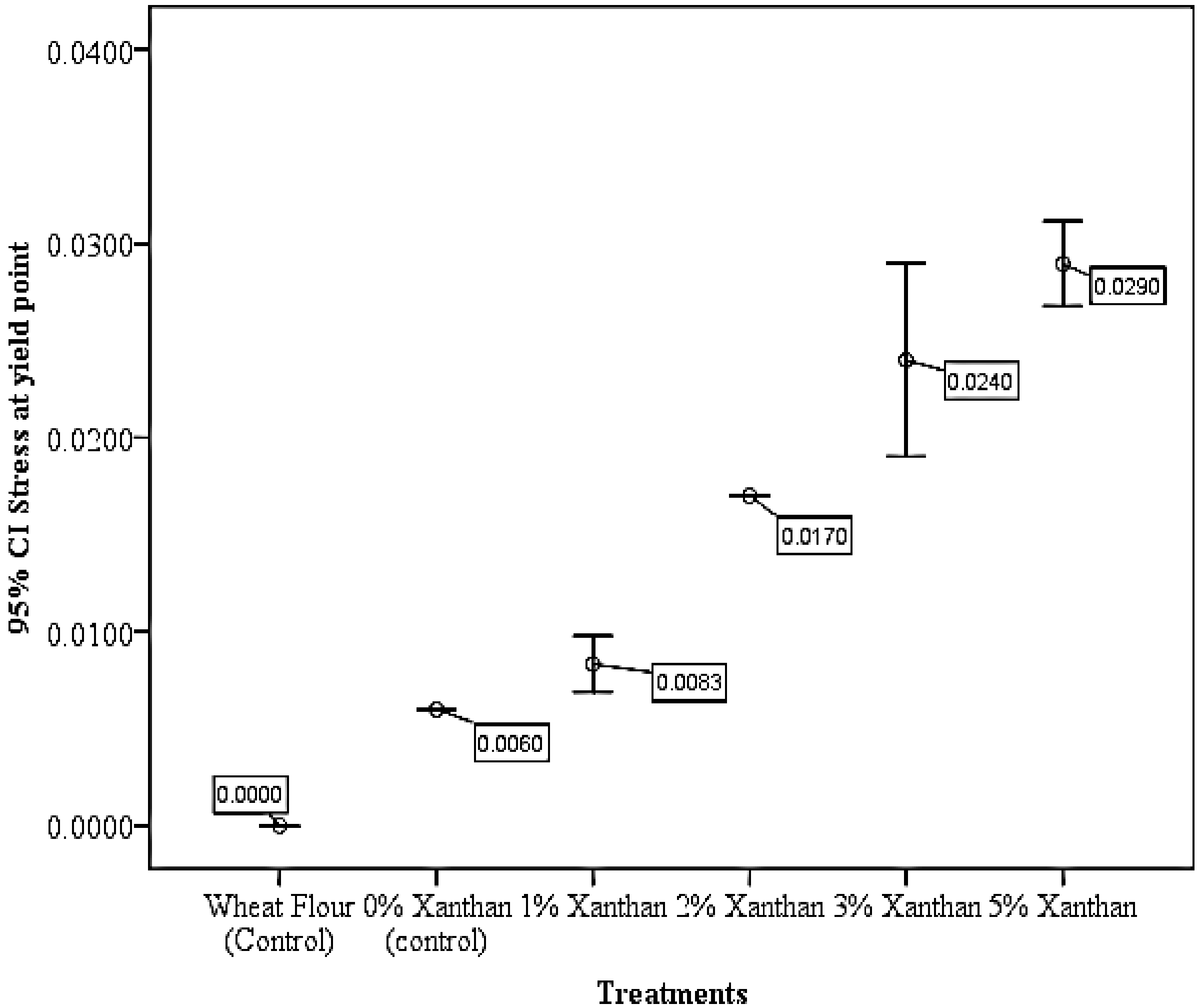

Figure 11. Effect of xanthan gum (0-5%) on the stress at yield point (mPa) applied on Gluten-Free dough compared to wheat flour dough

Table 7

Mean Elongation Parameter Values of Pizza Dough Treatments With Increasing Levels of Xanthan Gum Concentrations (0 - 5%; wheat flour control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

Elongation Parameters	Treatments	Mean	SD
Force at max. load (mN)	Wheat Flour (Control 1)	697.47 [a]	20.53
	0% Xanthan gum (control 2)	548.21 [a]	18.48
	1% Xanthan gum	766.54 [a]	79.63
	2% Xanthan gum	1566.43[b]	40.39
	3% Xanthan gum	2220.65 [c]	190.91
	5% Xanthan gum	2671.79 [d]	81.33
Extension at max. load (mm)	Wheat Flour (Control 1)	65[e]	8.98
	0% Xanthan gum (control 2)	1.92[a]	0.30
	1% Xanthan gum	4.68[b]	0.56
	2% Xanthan gum	9.61[c]	1.19
	3% Xanthan gum	11.92[d]	1.12
	5% Xanthan gum	10.27[cd]	0.58
Stress at yield point (mPa)	Wheat Flour (Control 1)	*	*
	0% Xanthan gum (control 2)	0.01[a]	0.00
	1% Xanthan gum	0.01[b]	0.00
	2% Xanthan gum	0.02[c]	0.00
	3% Xanthan gum	0.02[d]	0.00
	5% Xanthan gum	0.03[e]	0.00

* Yield point was not reached, N=18, n=3, $P < 0.05$

Puncture. Results demonstrated that addition of xanthan gum had a significant effect ($p < 0.05$) on the mean compression force (maximum load) and stress at yield point (at break) for the treatments tested (Table 8, Figure 12 and 13).

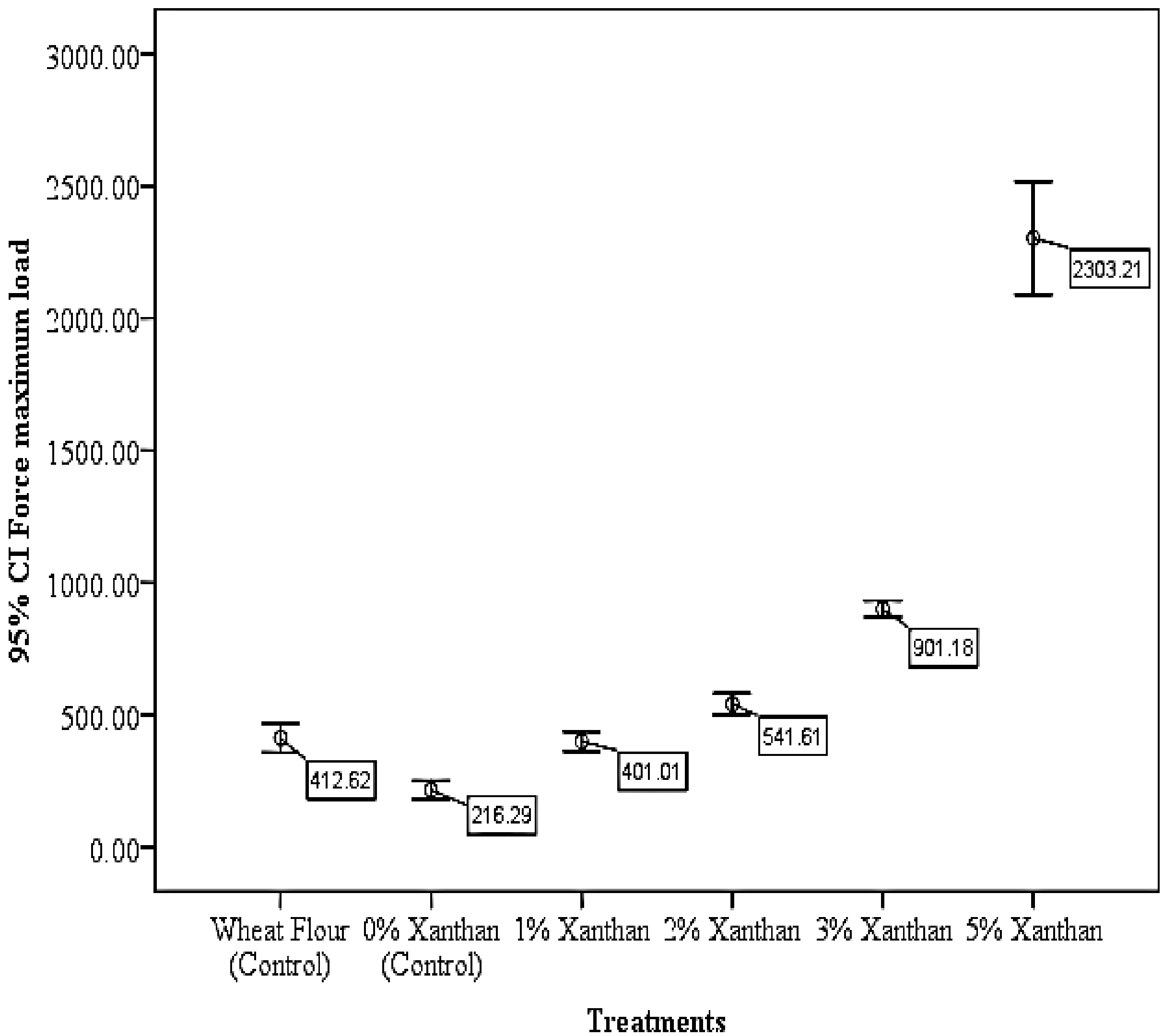

Figure 12. Effect of xanthan gum (0-5%) on the puncture force at maximum load (mN) exerted on Gluten-Free dough compared to wheat flour dough

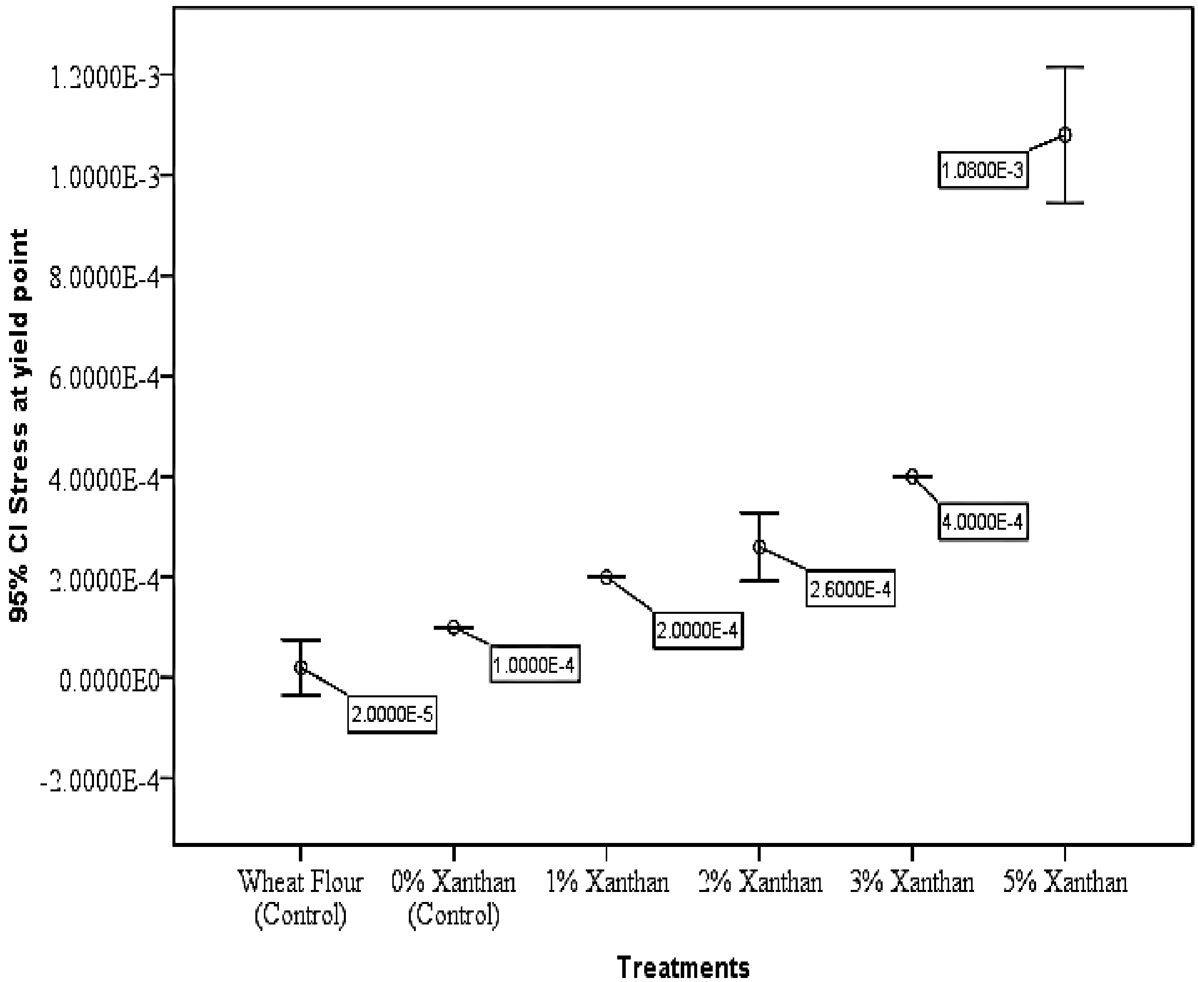

Figure 13. Effect of xanthan gum (0-5%) on the stress at yield point (mPa) exerted on Gluten-Free dough compared to wheat flour dough

Tukey's HSD showed that increasing levels of xanthan gum in the dough had a significant effect on increasing the compression force and stress at yield point (Table 8, Figure 12 and 13). There was no significant difference between wheat flour dough and 1% xanthan gum dough for both puncture force and stress at yield point. Also, addition of xanthan gum at 1% and 2% did not show any significant difference on stress at yield point during puncture (Table 8).

Table 8

Mean Puncture Parameter Values of Pizza Dough Treatments With Increasing Levels of Xanthan Gum Concentrations (0 - 5%; wheat flour control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD.

Puncture Parameters	Treatments	Mean	SD
Force at maximum load	Wheat Flour (Control 1)	412.62[b]	43.25
(mN)	0% Xanthan gum (control 2)	216.29[a]	28.47
	1% Xanthan gum	401.01[b]	29.83
	2% Xanthan gum	541.61[c]	32.33
	3% Xanthan gum	901.18[d]	24.49
	5% Xanthan gum	2303.21[e]	172.09
Stress at yield point (mPa)	Wheat Flour (Control 1)	*	*
	0% Xanthan gum (control 2)	0.0001[a]	0.00
	1% Xanthan gum	0.0002[b]	0.00
	2% Xanthan gum	0.0003[b]	0.00
	3% Xanthan gum	0.0004[c]	0.00
	5% Xanthan gum	0.0011[d]	0.00

*Yield point not reached, N=30, n=5, $P < 0$

TPA. Results demonstrated xanthan gum addition had a significant effect ($p < 0.05$) on the mean TPA parameters (adhesives, cohesiveness, hardness, springiness, chewiness and gumminess) for the tested treatments (Table 9a&b, Figure 14, 15, 16, 17, 18 and 19).

Table 9

Mean TPA Parameter Values of Pizza Dough Treatments With Increasing Levels of Xanthan Gum Concentrations (0 - 5%; wheat flour control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

TPA Parameters	Treatments	Mean	SD
Adhesiveness (mJ)	Wheat Flour (Control 1)	2.35^{b}	1.09
	0% Xanthan gum (Control 2)	0.17^{a}	0.03
	1% Xanthan gum	0.91^{a}	0.03
	2% Xanthan gum	1.21^{a}	0.52
	3% Xanthan gum	0.02^{a}	0.01
	5% Xanthan gum	0.22^{a}	0.20
Cohesiveness	Wheat Flour (Control 1)	0.29^{e}	0.02
	0% Xanthan (Control 2)	0.08^{b}	0.00
	1% Xanthan gum	0.05^{a}	0.00
	2% Xanthan gum	0.14^{c}	0.01
	3% Xanthan gum	0.14^{c}	0.02
	5% Xanthan gum	0.18^{d}	0.01
Hardness (N)	Wheat Flour (Control 1)	61.48^{a}	2.85
	0% Xanthan gum (Control 2)	69.15^{a}	1.12
	1% Xanthan gum	123.11^{b}	3.33
	2% Xanthan gum	136.03^{b}	11.19
	3% Xanthan gum	193.90^{c}	11.65
	5% Xanthan gum	301.58^{d}	9.57

N=18, n=3, $P < 0.05$

Tukey's HSD for the TPA measurements showed that increasing levels of xanthan gum had the following effects on the GF dough:

Adhesiveness. GF dough (0% xanthan) and wheat dough had significantly different adhesiveness (Table 9). There was no significant difference in adhesiveness (mJ) in GF with increasing levels of xanthan gum (Table 9 and Figure 14).

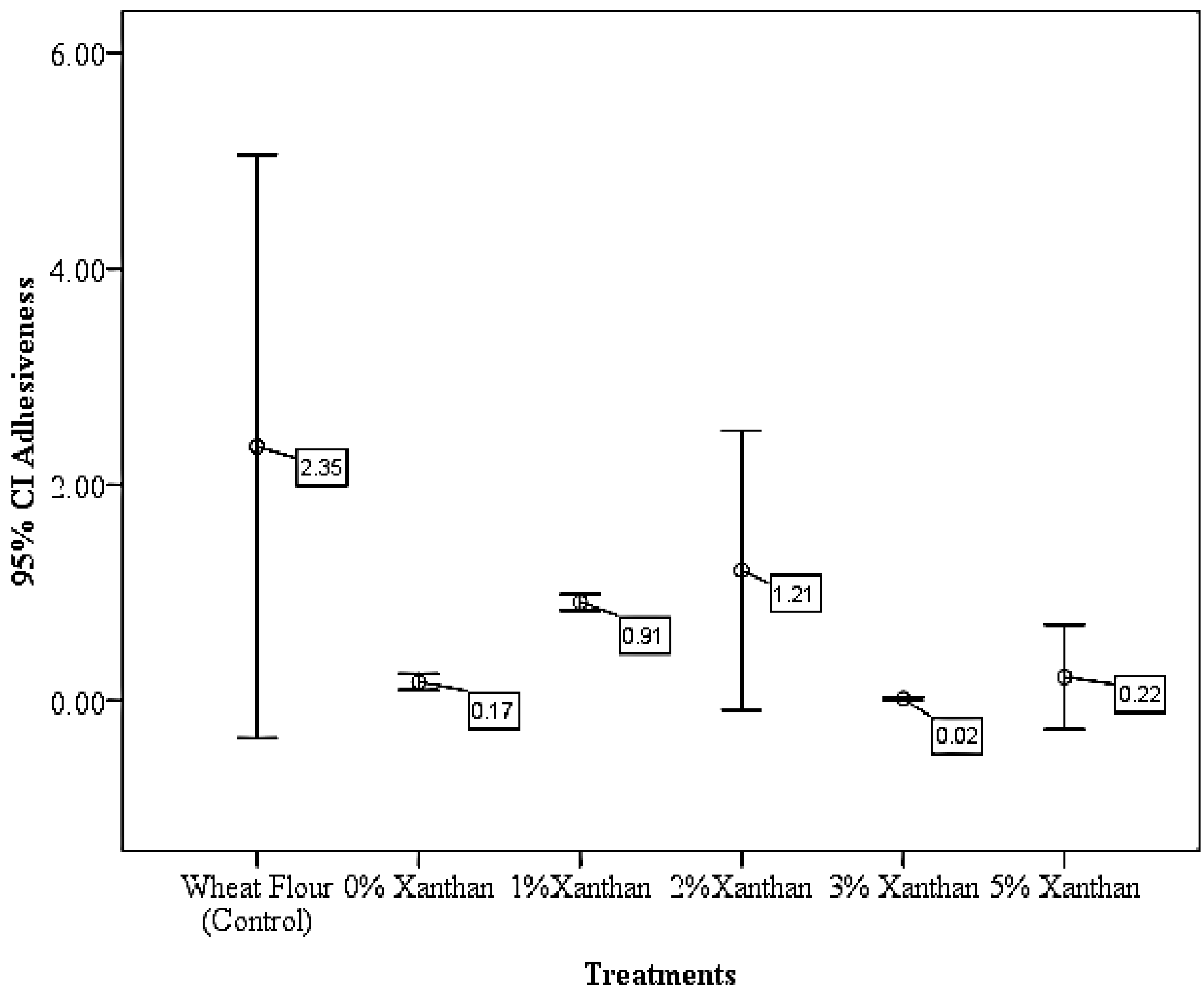

Figure 14. Effect of xanthan gum addition (0-5%) on adhesiveness (mJ) of GF dough compared to wheat flour dough

Cohesiveness. GF dough with increasing levels of xanthan gum showed significantly increasing cohesiveness values. There was no significant difference in cohesiveness of GF dough with 2 and 3% added xanthan gum (Table 9 and Figure 15).

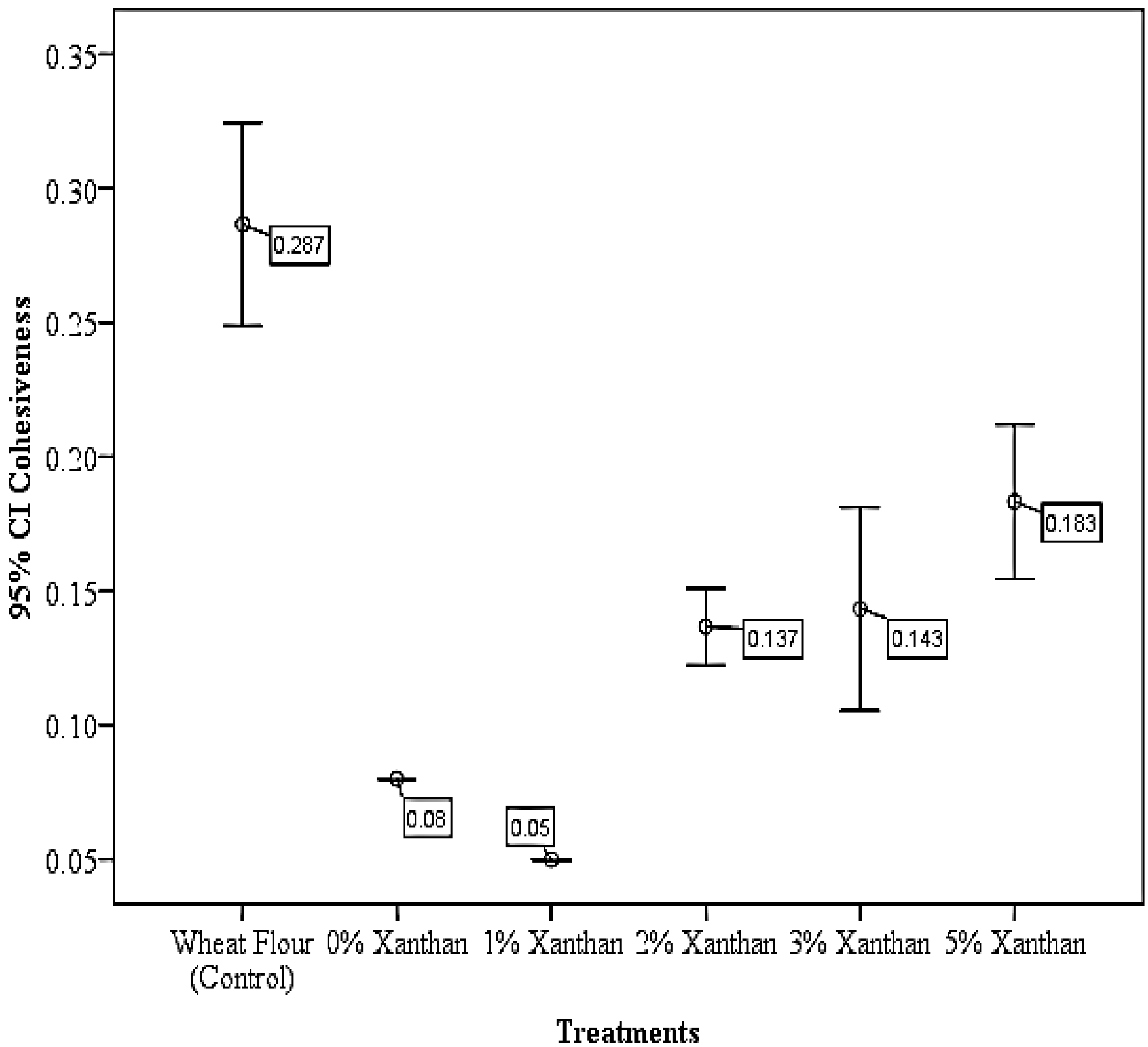

Figure 15. Effect of xanthan gum addition (0-5%) on cohesiveness of GF dough compared to wheat flour dough

Hardness. GF dough with increasing levels of xanthan gum showed significantly increasing hardness values. However, increasing xanthan gum levels between 1% and 2% had no significant difference in the GF dough. Also, wheat flour dough and 0% xanthan gum dough had no significant difference (Table 9 and Figure 16).

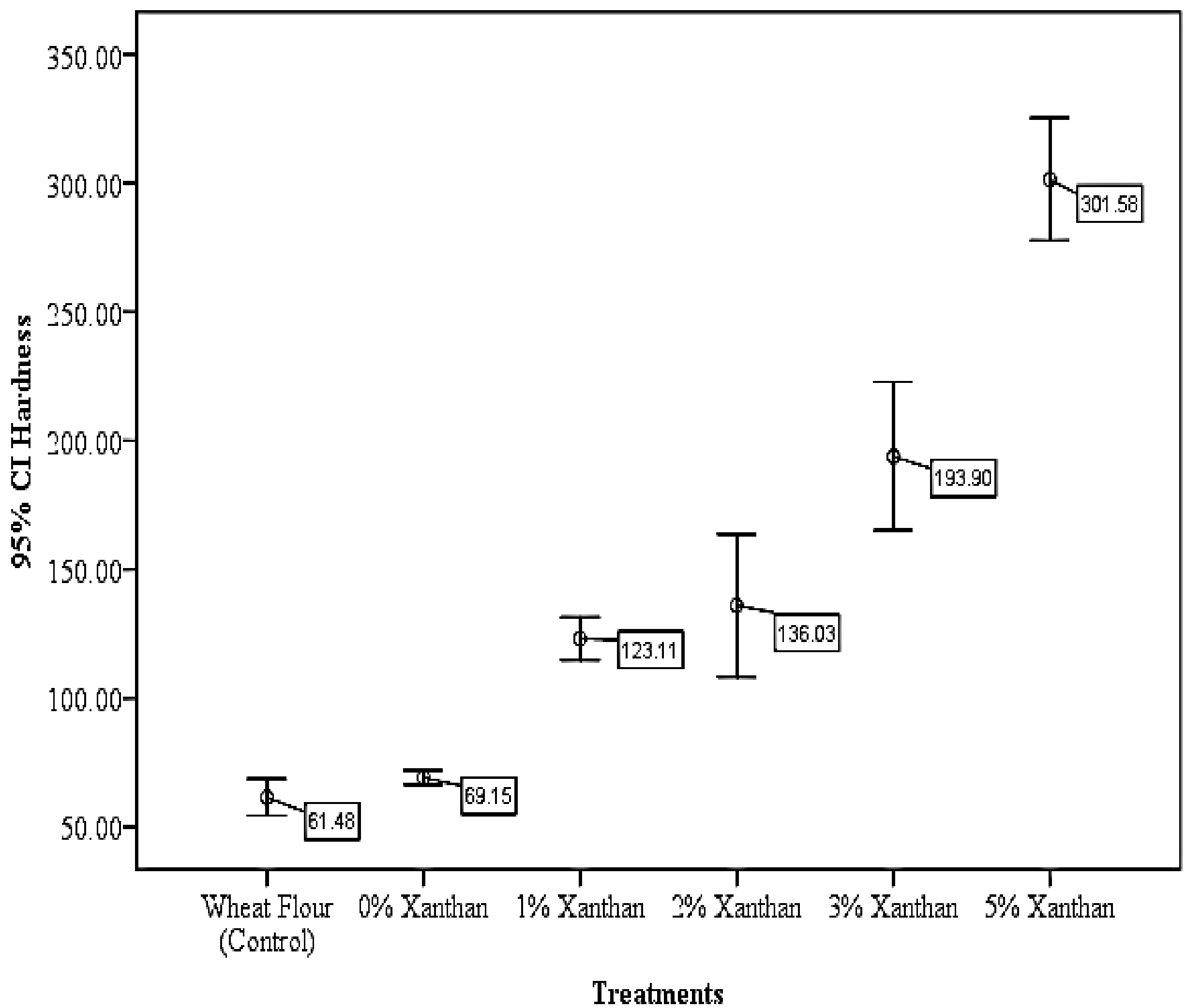

Figure 16. Effect of xanthan gum addition (0-5%) on hardness (N) of GF dough compared to wheat flour dough

Springiness. GF dough with increasing levels of xanthan gum showed significantly increasing springiness values. However, adding 1%, 2% and 3% xanthan gum to the GF doughs did not show any significantly difference (Table 10 and Figure 17).

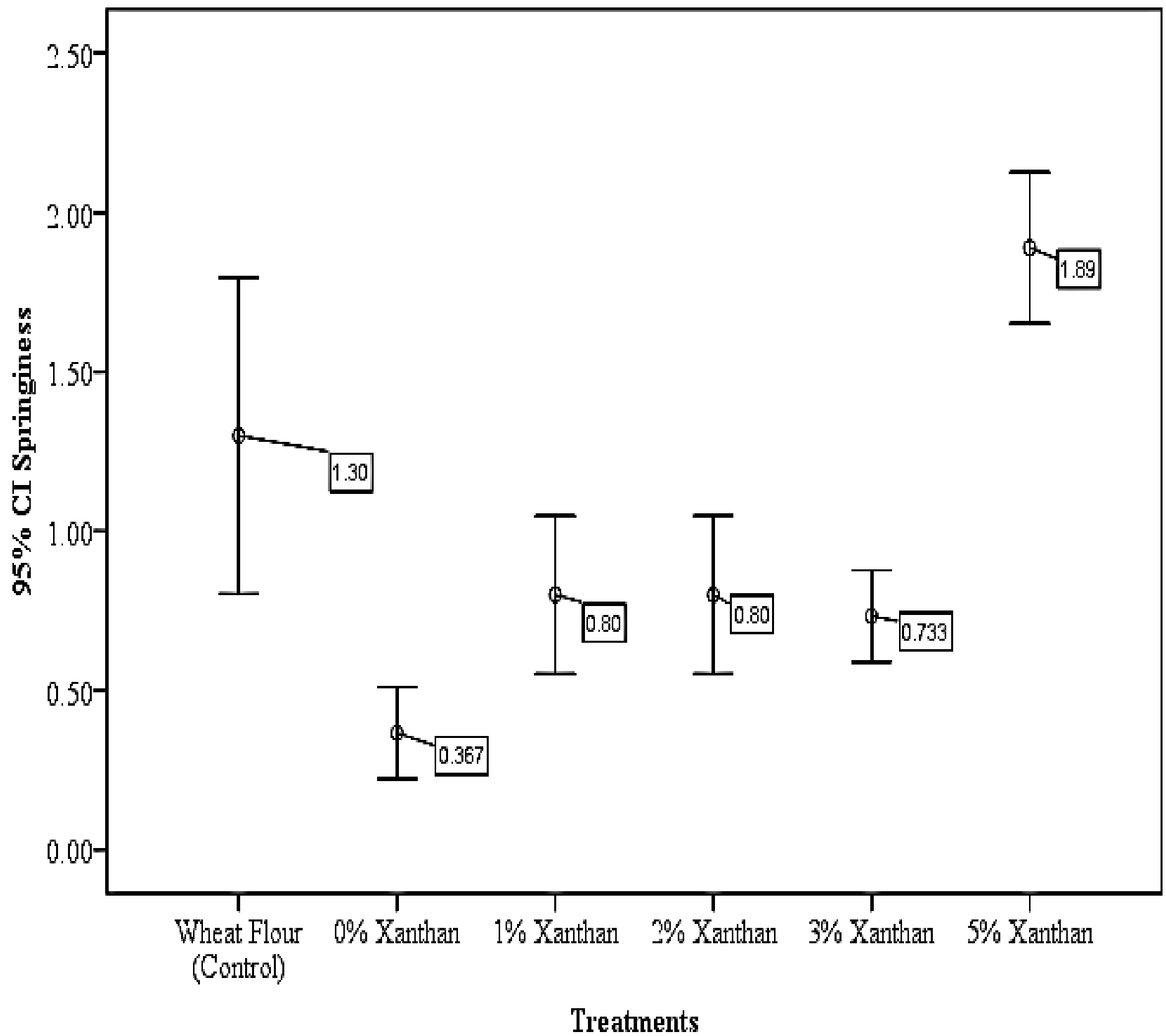

Figure 17. Effect of xanthan gum addition (0-5%) on springiness (mm) of GF dough compared to wheat flour dough

Chewiness. Addition of xanthan gum to the GF dough significantly increased chewiness. However, addition of 0%, 1% and 2% xanthan gum to the GF doughs did not show significantly difference in chewiness. Also, there was no significant difference between wheat dough, 2%, and 3% xanthan gum GF doughs (Table 10 and Figure 18).

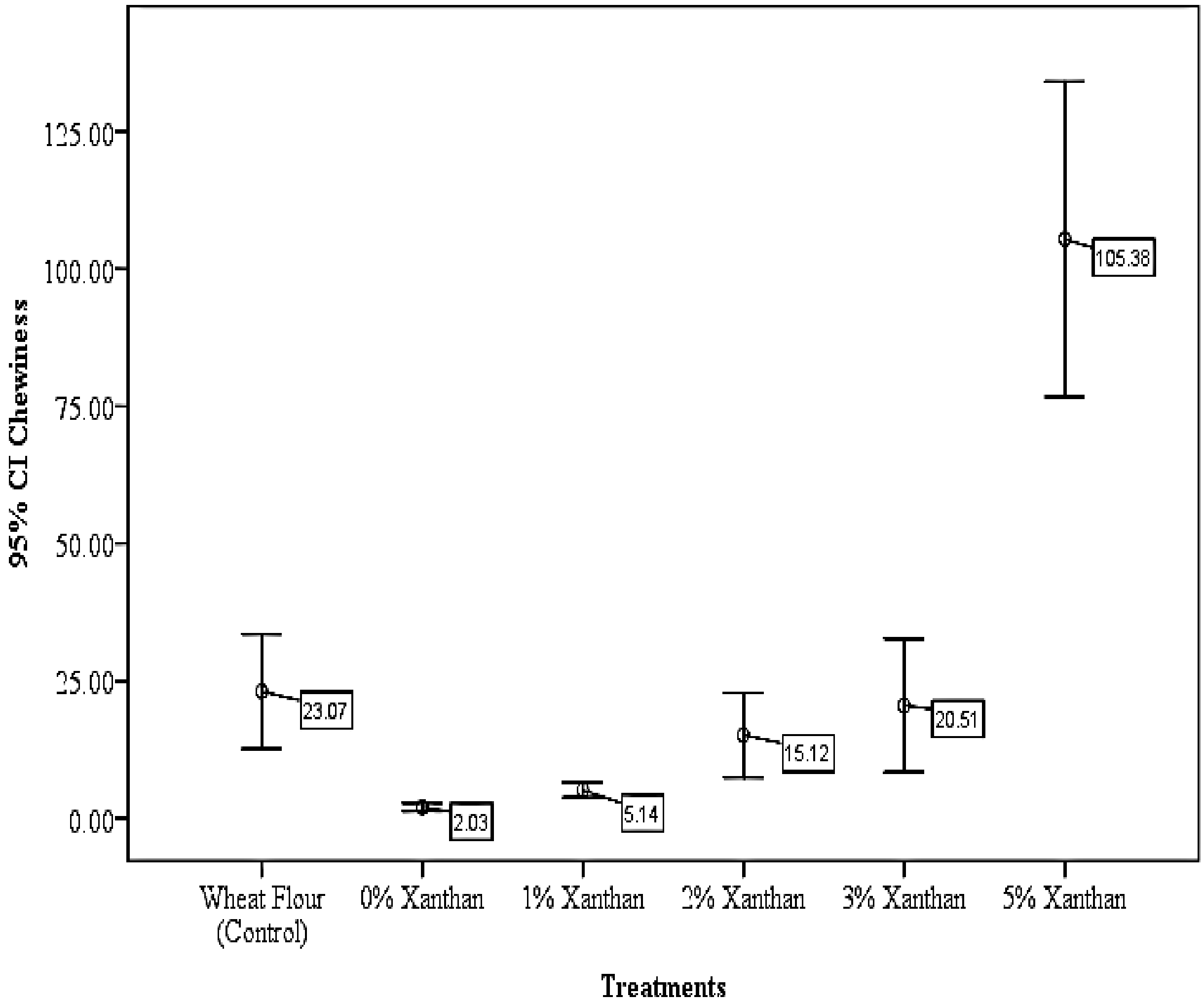

Figure 18. Effect of xanthan gum addition (0-5%) on chewiness (mJ) of GF dough compared to wheat flour dough

Table 10

Mean TPA Parameter Values of Pizza Dough Treatments With Increasing Levels of Xanthan Gum Concentrations (0 - 5%; wheat flour control) Continued. Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

TPA parameters	Treatments	Mean	S.D
Springiness (mm)	Wheat Flour (Control 1)	1.30^{c}	0.20
	0% Xanthan gum (Control 2)	0.37^{a}	0.06
	1% Xanthan gum	0.80^{b}	0.10
	2% Xanthan gum	0.80^{b}	0.10
	3% Xanthan gum	0.73^{b}	0.06
	5% Xanthan gum	1.89^{c}	0.10
Chewiness (mJ)	Wheat Flour (Control 1)	23.07^{b}	4.21
	0% Xanthan gum (Control 2)	2.03^{a}	0.30
	1% Xanthan gum	5.14^{a}	0.56
	2% xanthan gum	15.12^{ab}	3.10
	3% Xanthan gum	20.51^{b}	4.90
	5% Xanthan gum	105.38^{c}	11.55
Gumminess (N)	Wheat Flour (Control 1)	17.70^{b}	0.90
	0% Xanthan gum (Control 2)	5.54^{a}	0.24
	1% Xanthan gum	6.44^{a}	0.11
	2% Xanthan gum	18.86^{b}	2.40
	3% Xanthan gum	27.75^{c}	4.42
	5% Xanthan gum	55.66^{d}	3.61

N=18, n=3, $P < 0.05$

Gumminess. Addition of xanthan gum significantly increased gumminess of the GF dough. The authors observed no significant difference between 0% and 1% xanthan gum GF doughs, and between wheat dough and 2% xanthan gum GF dough (Table 10 and Figure 19).

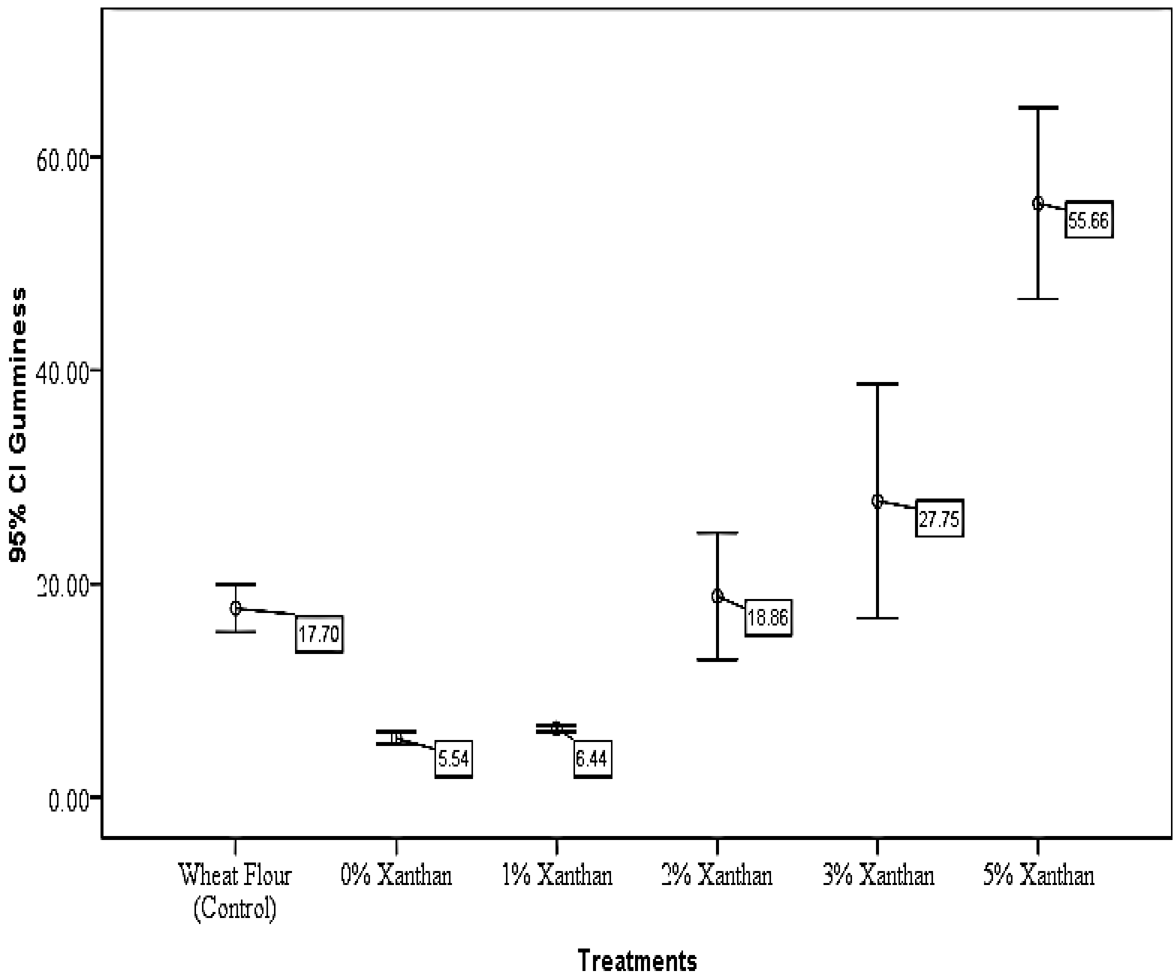

Figure 19. Effect of xanthan gum addition (0-5%) on gumminess (N) of GF dough compared to wheat four dough

Dairy Ingredients

Whey addition.

Elongation. Results demonstrated that increasing whey protein had significant effect ($p < 0.05$) on the mean elongation force (at maximum load), maximum extension length, and stress at yield point (at break) for the treatments tested (Table 11, Figure 20, 21 and 22).

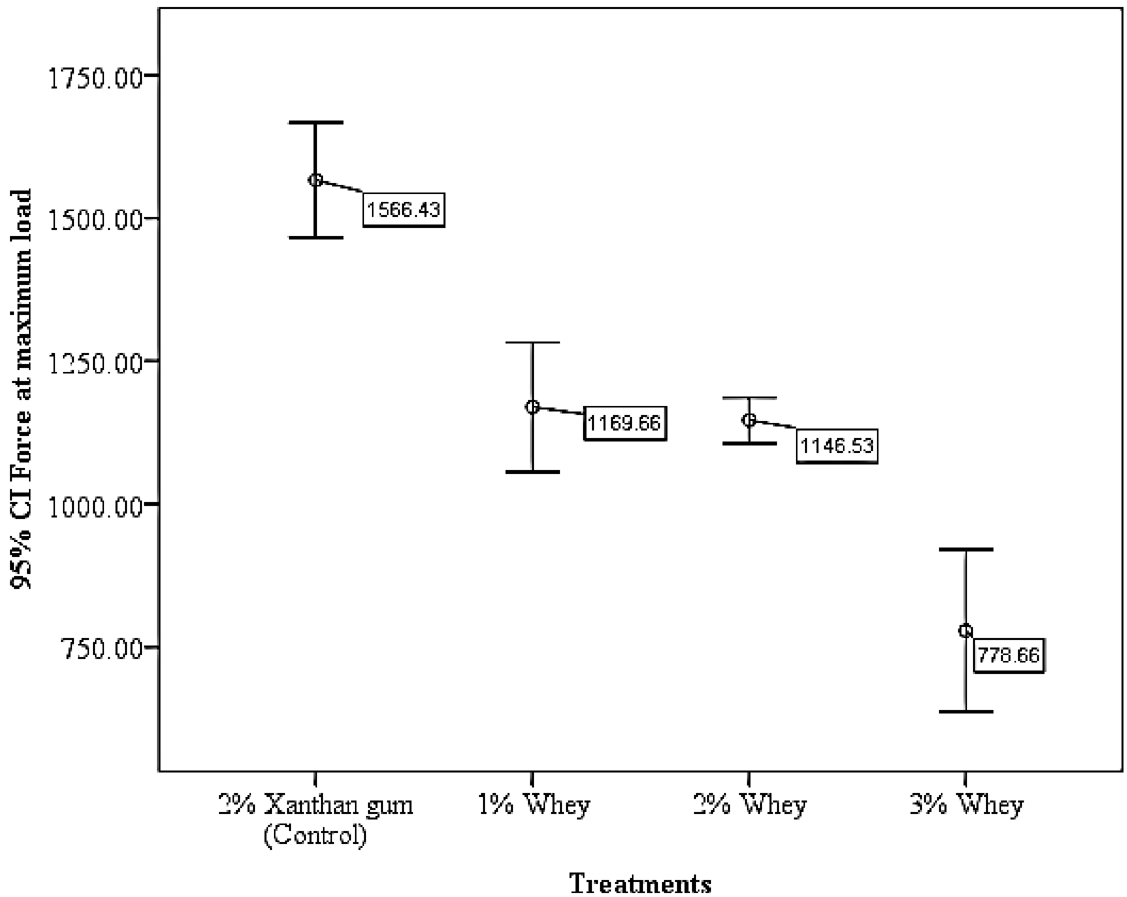

Figure 20. Effect of whey protein (1-3%) on the elongation force at maximum load (mN) applied on Gluten-Free dough containing 2% xanthan gum

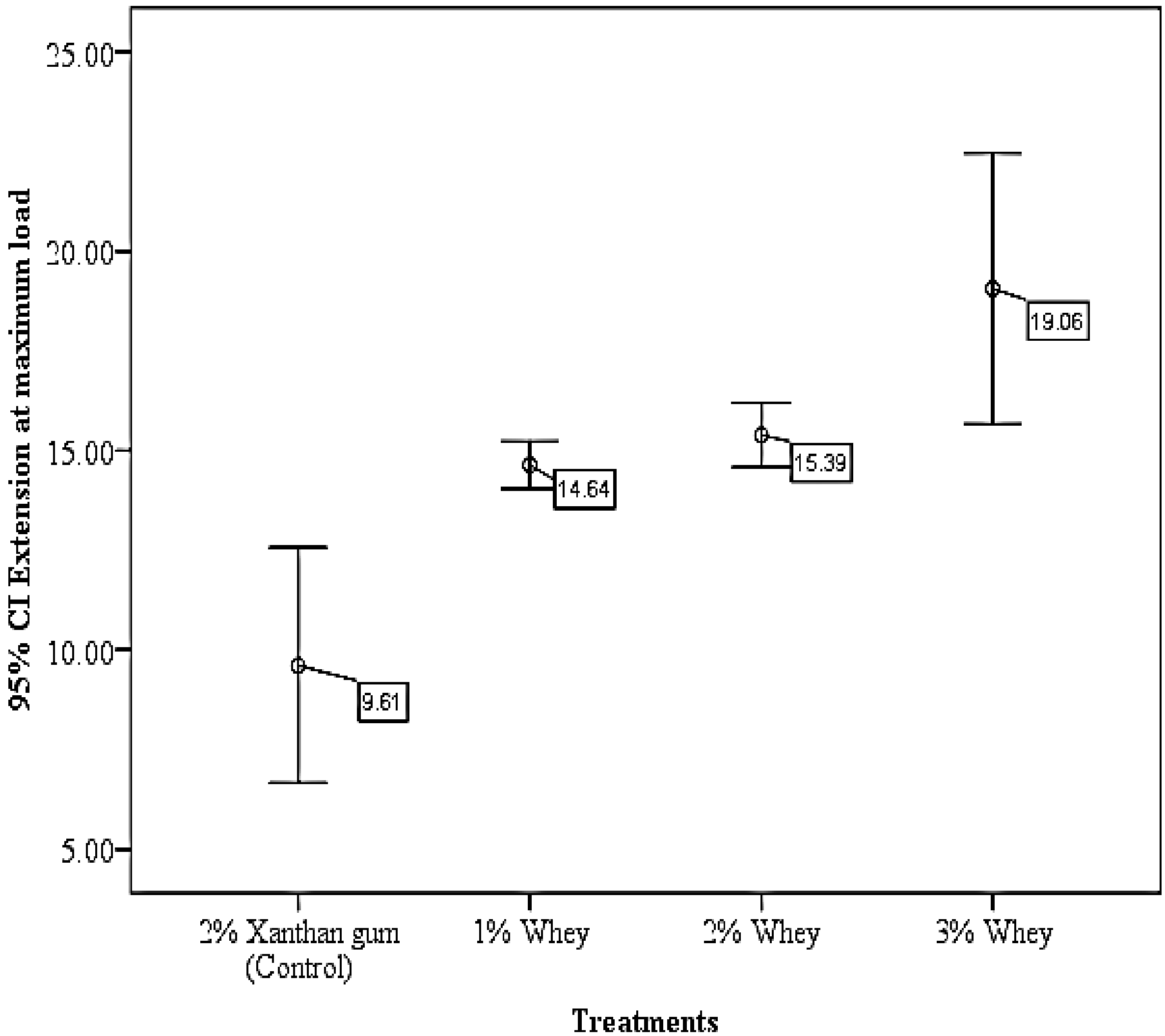

Figure 21. Effect of whey protein (1-3%) on the extension at maximum load (mm) of stretched Gluten-Free dough containing 2% xanthan gum

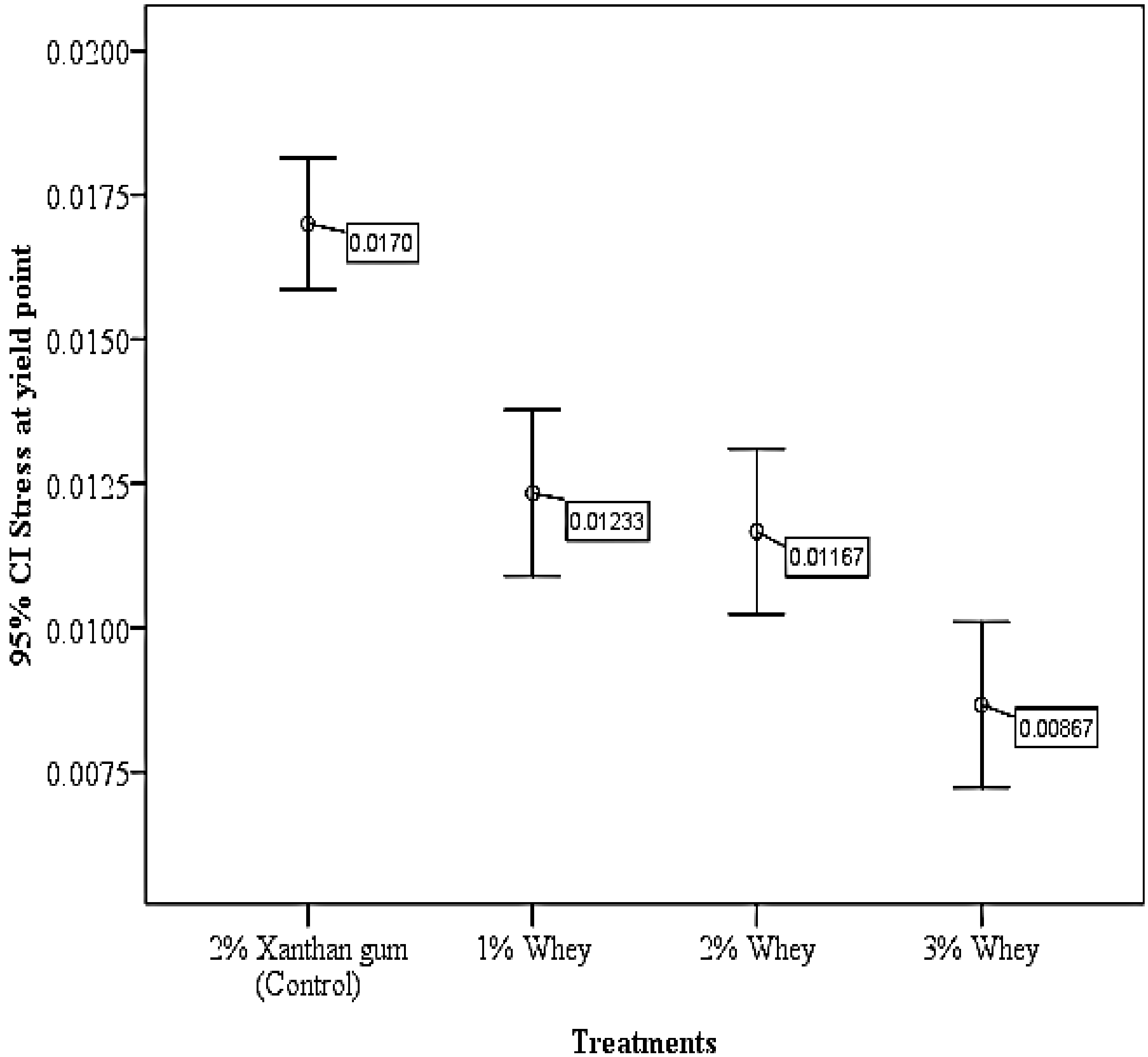

Figure 22. Effect of whey protein (1-3%) on the stress at yield point (mPa) applied on Gluten-Free dough containing 2% xanthan gum

Table 11

Mean Elongation Parameter Values of Pizza Dough Treatments With Increasing Levels of Whey Protein Concentrations (1 - 3%; 2% xanthan gum control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

Elongation Parameters	Treatments	Mean	S.D
Force at max. load (mN)	2% Xanthan gum (Control)	1566.43[c]	40.39
	1% Whey	1169.66[b]	45.36
	2% Whey	1146.53[b]	16.00
	3% Whey	778.66[a]	57.37
Extension at max. load (mm)	2% Xanthan gum (Control)	9.61[a]	1.19
	1% Whey	14.64[b]	0.24
	2% Whey	15.39[b]	0.33
	3% Whey	19.06[c]	1.37
Stress at yield point (mPa)	2% Xanthan gum (Control)	0.02[c]	0.00
	1% Whey	0.01[b]	0.00
	2% Whey	0.01[b]	0.00
	3% Whey	0.01[a]	0.00

N=12, n=3, $P < 0.05$

Tukey's HSD demonstrated that increasing of whey proteins led to subsequent reduction in elongation force and stress at yield point of the GF dough. On the other hand, increasing whey protein resulted in increase of extension length of the GF dough (Table 11, Figure 20, Figure 21 and Figure 22). Samples with 1% and 2% whey protein had no significant difference in terms of elongation force required to stretch the GF dough to break point, extension at maximum load and stress at yield point (Table 11).

Puncture. Results demonstrated that increasing whey protein had a significant effect ($p < 0.05$) on the mean compression force (maximum load) and stress at yield point (at break) for the treatments tested (Table 12, Figure 23 and 24).

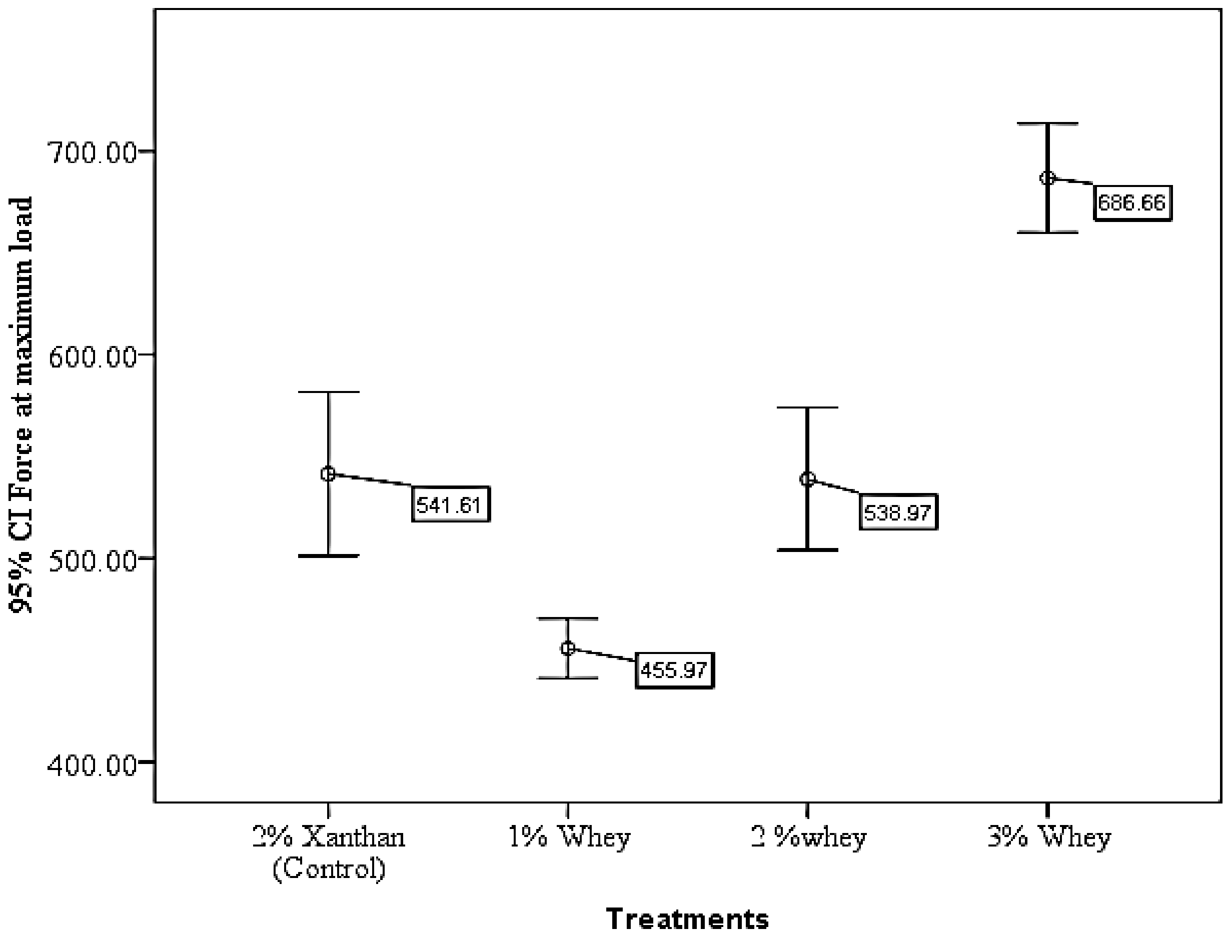

Figure 23. Effect of whey protein (1-3%) on the puncture force at maximum load (mN) exerted on Gluten-Free dough containing 2% xanthan gum

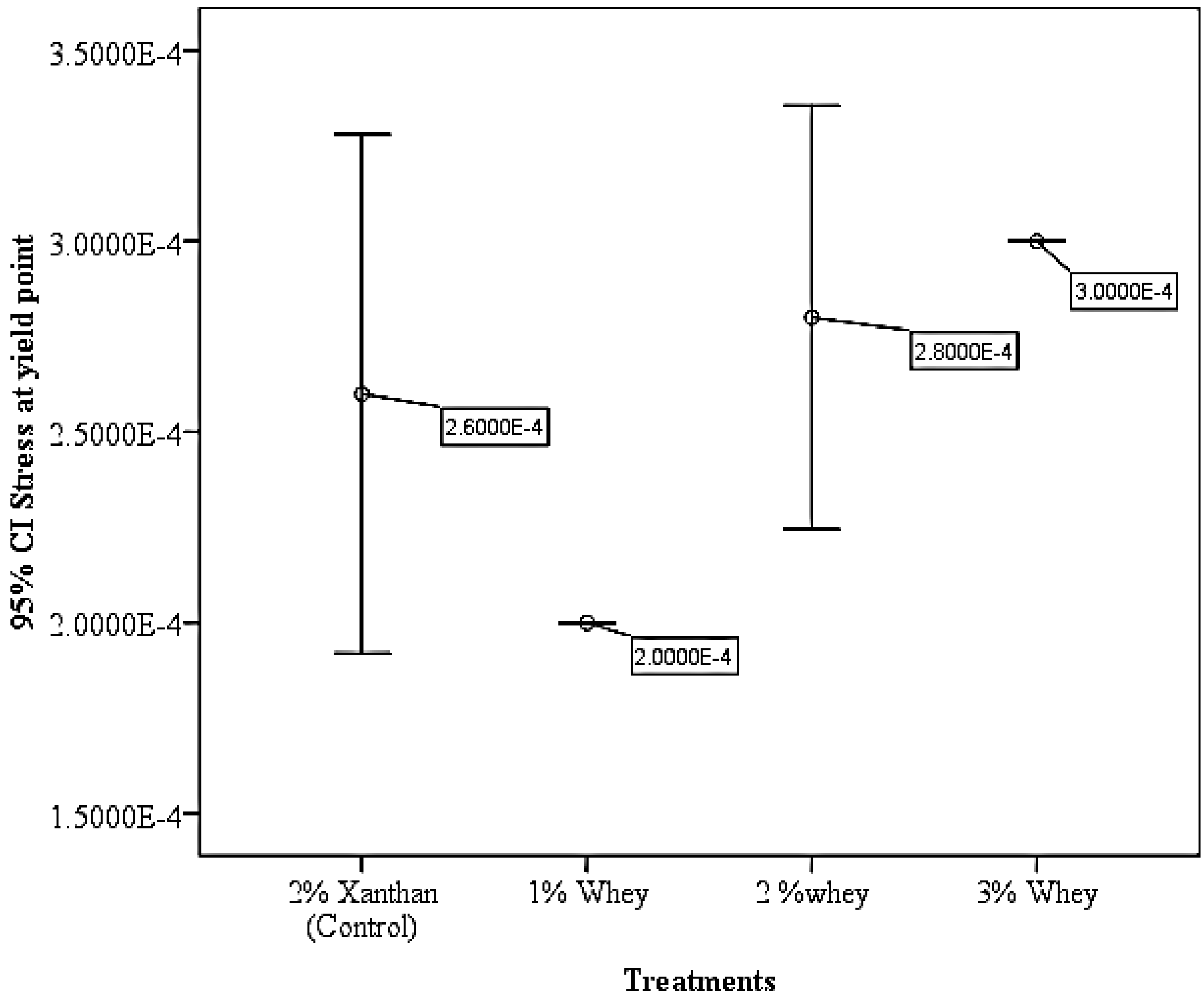

Figure 24. Effect of whey protein (1-3%) on the stress at yield point (mPa) applied on Gluten-Free dough containing 2% xanthan gum

Tukey's HSD indicated that addition of whey protein in the dough had a significant effect on reducing the compression force and stress at yield point of the GF dough (Table 12, Figure 23 and Figure 24). However, beyond a threshold of 2% whey protein addition compression force started to increase. The force required to puncture dough with whey protein added at 2% was not statistically different from that of 2% xanthan gum (control). Also, there was no statistically significant difference in stress at yield point between dough added with 0% (control), 2% and that with 3% whey (Table 12).

Table 12

Mean Puncture Parameter Values of Pizza Dough Treatments With Increasing Levels of Whey Protein Concentrations (1 - 3%; 2% xanthan gum control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

Puncture Parameters	Treatments	Mean	S.D
Force at maximum load (mN)	2% Xanthan (Control)	541.61^{b}	32.33
	1% Whey	455.97^{a}	11.91
	2 %whey	538.97^{b}	28.24
	3% Whey	686.66^{c}	21.62
Stress at yield point (mPa)	2% Xanthan (Control)	0.0003^{b}	0.00
	1% Whey	0.0002^{a}	0.00
	2 %whey	0.0003^{b}	0.00
	3% Whey	0.0003^{b}	0.00

N=20, n=5, P < 0. 05

TPA. Results demonstrated that addition of whey protein had a significant effect ($p < 0.05$) on the mean TPA parameters (adhesives, cohesiveness, hardness and gumminess) for the tested treatments. However, springiness and chewiness were not statistically significant (Table 13, Figure 25, Figure 26, Figure 27 and Figure 28).

Tukey's HSD for the TPA measurements showed that increasing levels of whey protein had the following effects on the GF dough:

Table 13

Mean TPA Parameter Values of Pizza Dough Treatments With Increasing Levels of Whey Protein Concentrations (1 - 3%; 2% xanthan gum control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

TPA Parameters	Treatments	Mean	S.D
Adhesiveness (mJ)	2% Xanthan gum (control)	1.21[a]	0.52
	1% Whey	1.59[a]	0.20
	2% Whey	1.10[a]	0.23
	3% Whey	8.56[b]	1.23
Cohesiveness	2% Xanthan gum (control)	0.14[ab]	0.01
	1% Whey	0.13[ab]	0.015
	2% Whey	0.11[a]	0.00
	3% Whey	0.15[b]	0.02
Hardness (N)	2% Xanthan gum (control)	136.03[b]	11.19
	1% Whey	105.27[a]	3.31
	2% Whey	135.19[b]	5.53
	3% Whey	144.86[b]	12.64
Gumminess (N)	2% Xanthan gum (control)	18.86[b]	2.40
	1% Whey	14.13[a]	2.10
	2% Whey	15.07[a]	0.43
	3% Whey	22.51[b]	0.82

N=12, n=3, P < 0. 05

Adhesiveness.

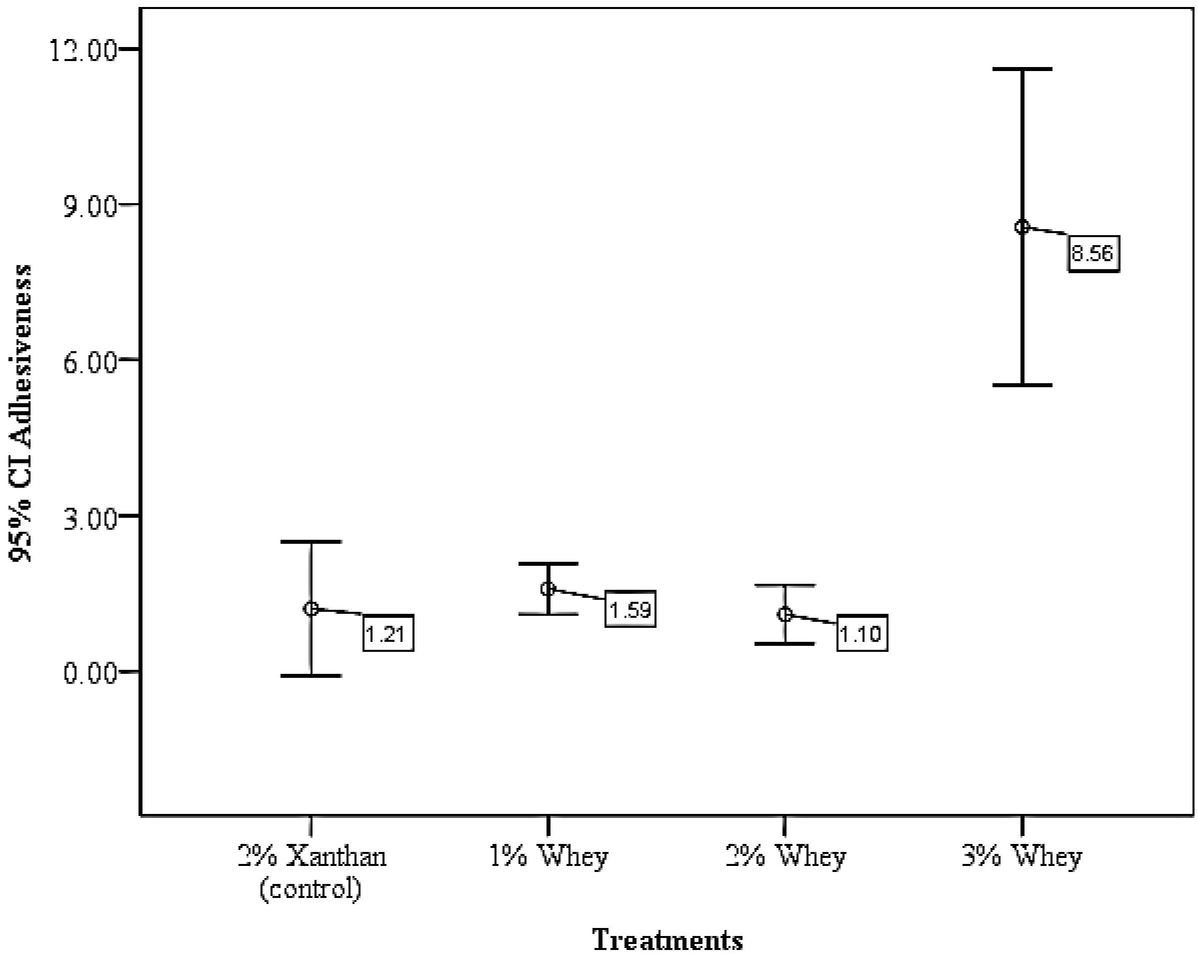

Figure 25. Effect of whey protein (1-3%) on adhesiveness (mJ) of GF dough containing 2% xanthan gum

Addition of whey proteins significantly increased adhesiveness of the dough. There was no significant difference between GF doughs with 2% xanthan gum (control), 1% and 2% whey proteins (Table 13 and Figure 25).

Cohesiveness.

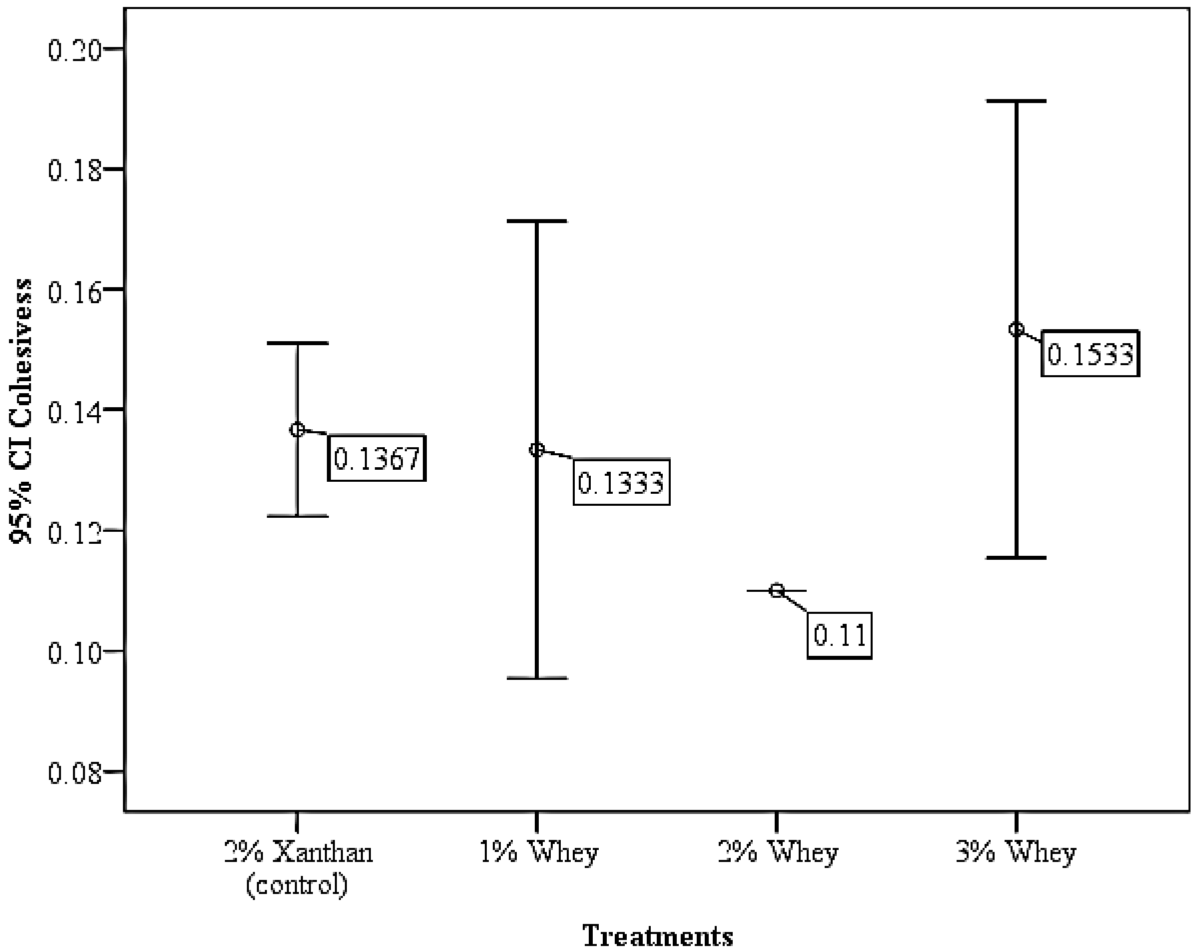

Figure 26. Effect of whey protein (1-3%) on cohesiveness of GF dough containing 2% xanthan gum

Adding whey proteins significantly increased cohesiveness of the GF dough. The 2% xanthan gum dough (control), 1% and 2% whey dough were not significantly different (Table 13 and Figure 26). However, only 1% whey dough was significantly different from 3% whey dough.

Hardness.

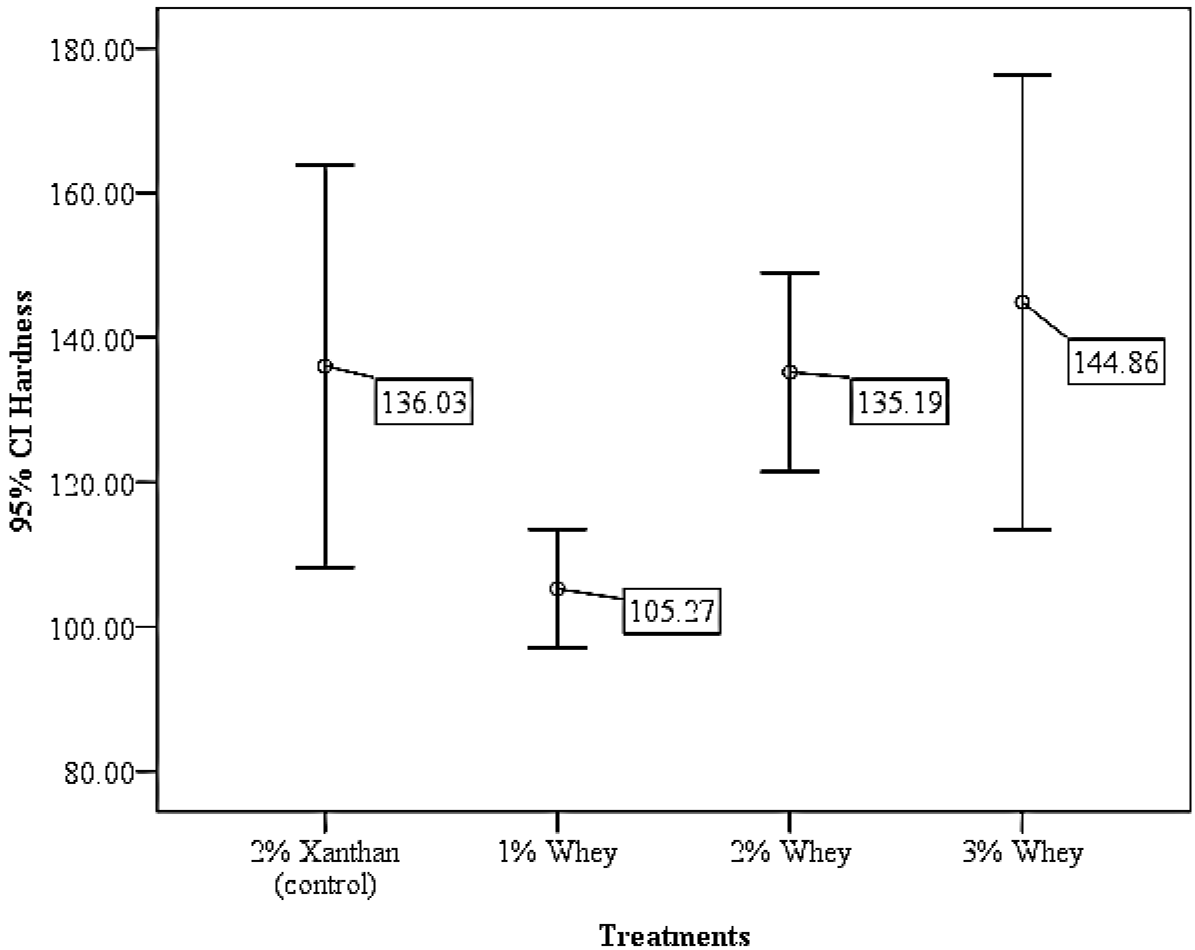

Figure 27. Effect of whey protein (1-3%) on hardness (N) of GF dough containing 2% xanthan gum

Addition of whey protein significantly reduced hardness of the GF dough. There was no significant difference between 2% xanthan gum (control), 2% and 3% added whey dough (Table 13 and Figure 27).

Gumminess.

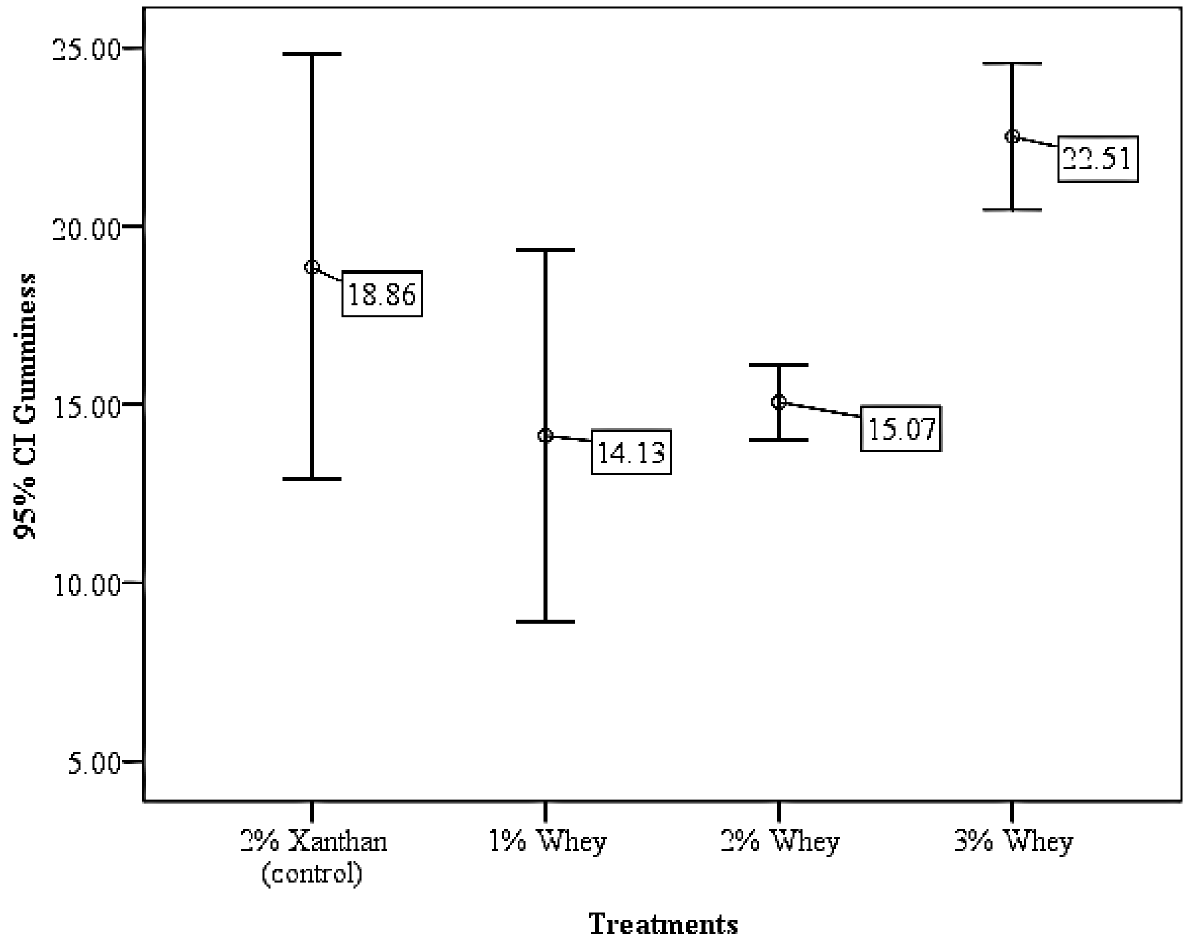

Figure 28. Effect of whey protein (1-3%) on gumminess (N) of GF dough containing 2% xanthan gum

Addition of whey protein significantly increased gumminess of the GF dough. However, addition of 1% whey protein had no significant difference from the 2% whey protein. Also, increasing whey protein to 3% had no significant difference from 2% xanthan gum (control) (Table 13 and Figure 28).

NFDM addition.

Elongation. Addition of NFDM had a significant effect ($p < 0.05$) on the mean elongation force (at maximum load), maximum extension length, and stress at yield point (at break) for the treatments tested (Table 14 Figure 29, 30, and 31).

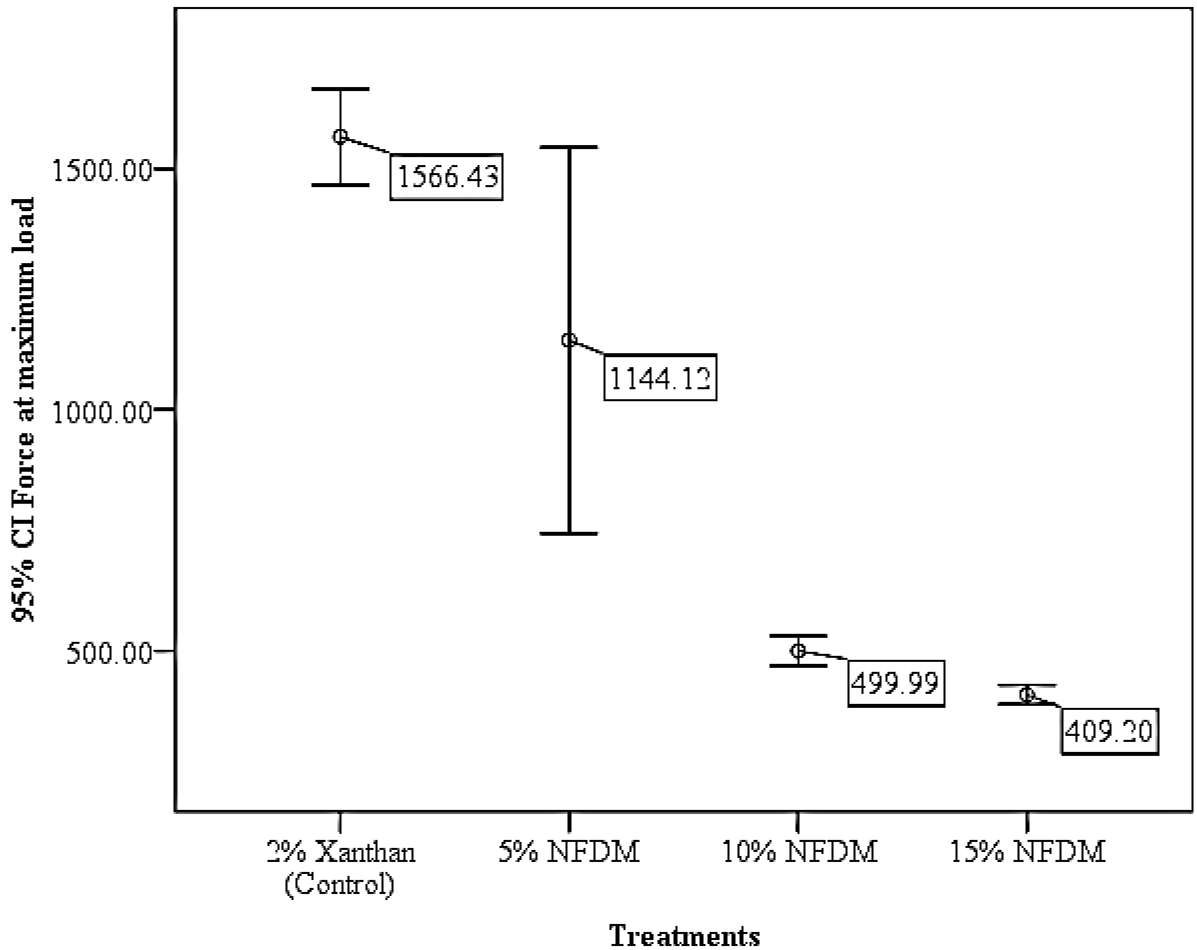

Figure 29. Effect of NFDM (5-15%) on the elongation force at maximum load (mN) applied on Gluten-Free dough containing 2% xanthan gum

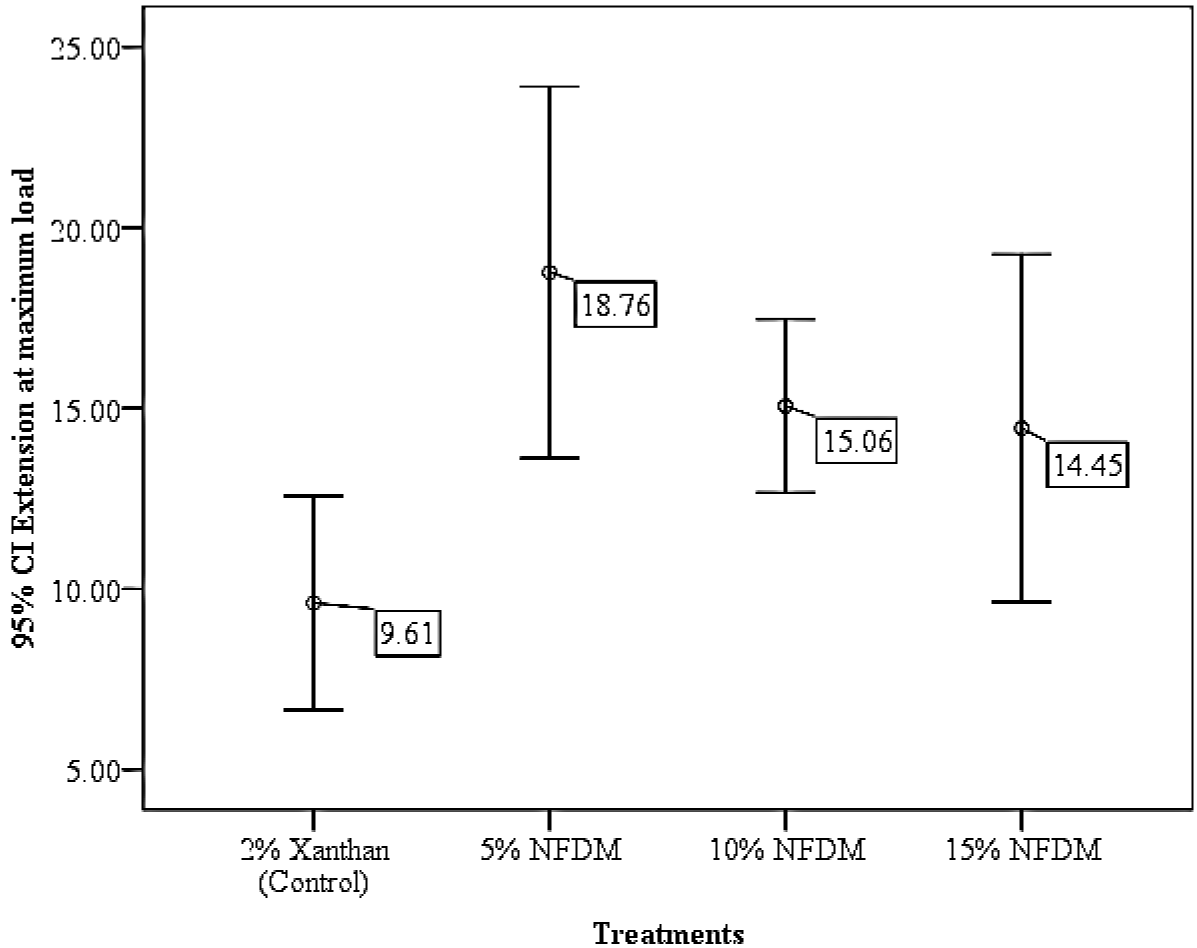

Figure 30. Effect of NFDM (5-15%) on the extension at maximum load (mm) of stretched Gluten-Free dough containing 2% xanthan gum

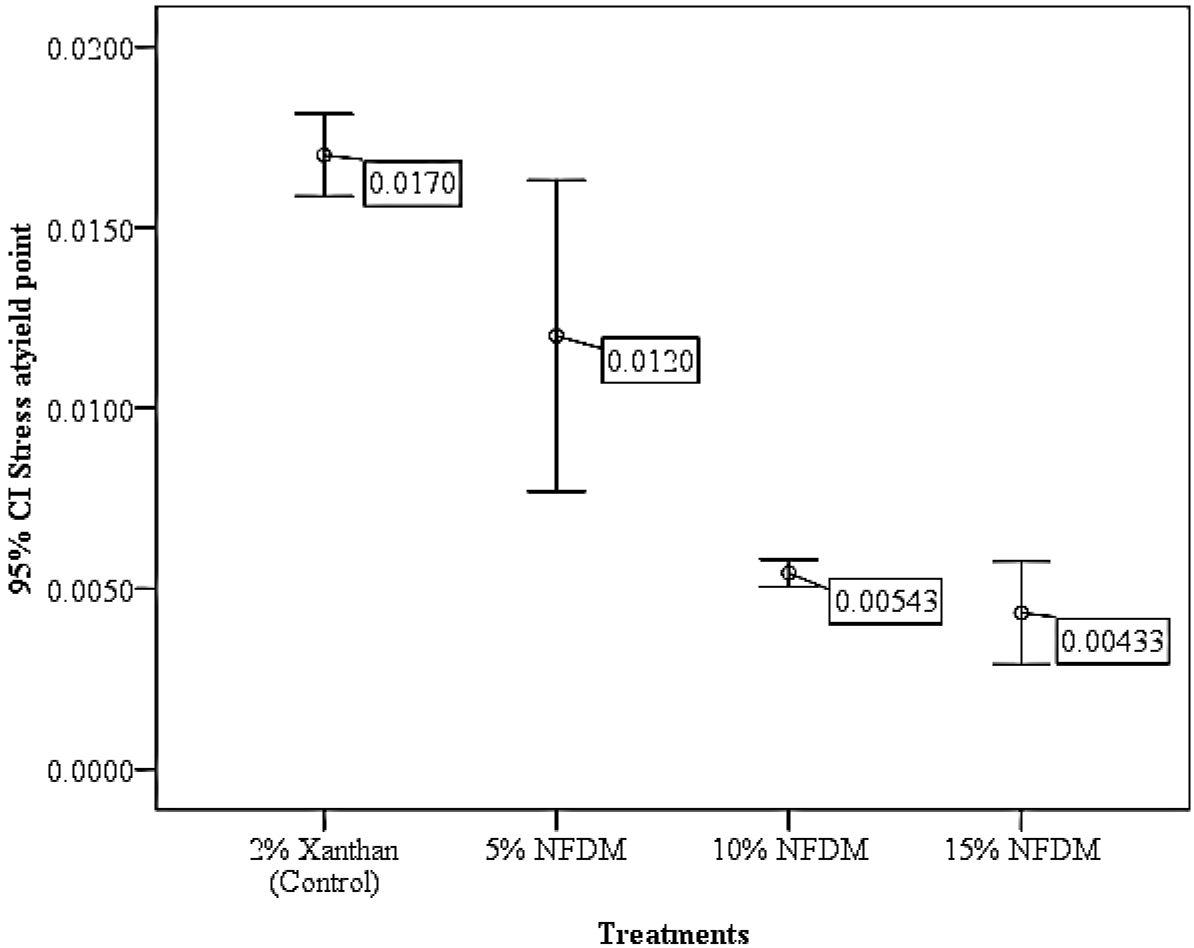

Figure 31. Effect of NFDM (5-15%) on the stress at yield point (mPa) applied on Gluten-Free dough containing 2% xanthan gum

Table 14

Mean Elongation Parameter Values of Pizza Dough Treatments With Increasing Levels of NFDM Concentrations (5 - 15%; 2% Xanthan Gum Control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

Elongation Parameters	Treatments	Mean	SD
Force at max. load (mN)	2% Xanthan (Control)	1566.43[c]	40.39
	5% NFDM	1144.12[b]	161.25
	10% NFDM	499.99a	12.31
	15% NFDM	409.20[a]	8.08
Extension at max. load (mm)	2% Xanthan (Control)	9.61[a]	1.19
	5% NFDM	18.76[c]	2.07
	10% NFDM	15.06[b]	0.97
	15% NFDM	14.45[b]	1.93
Stress at yield point (mPa)	2% Xanthan (Control)	0.02[c]	0.00
	5% NFDM	0.01[b]	0.00
	10% NFDM	0.01[a]	0.00
	15% NFDM	0.00[a]	0.00

N=12, n=3, P < 0. 05

Tukey's HSD results demonstrated that increasing levels of NFDM in the GF dough had a significant effect in reducing the elongation force and stress at yield point, whereas, increasing extension length of the GF dough (Table 14, Figure 29, 30 and 31). Gluten-free dough with 10% and 15% NFDM had no significant difference on all elongation test parameters (elongation force at maximum load, extension at maximum load and stress at yield point).

Puncture. Adding NFDM to the GF dough had significant effect ($p < 0.05$) on the mean compression force (maximum load) and stress at yield point (at break) for the treatments tested (Table 15, Figure 32 and 33).

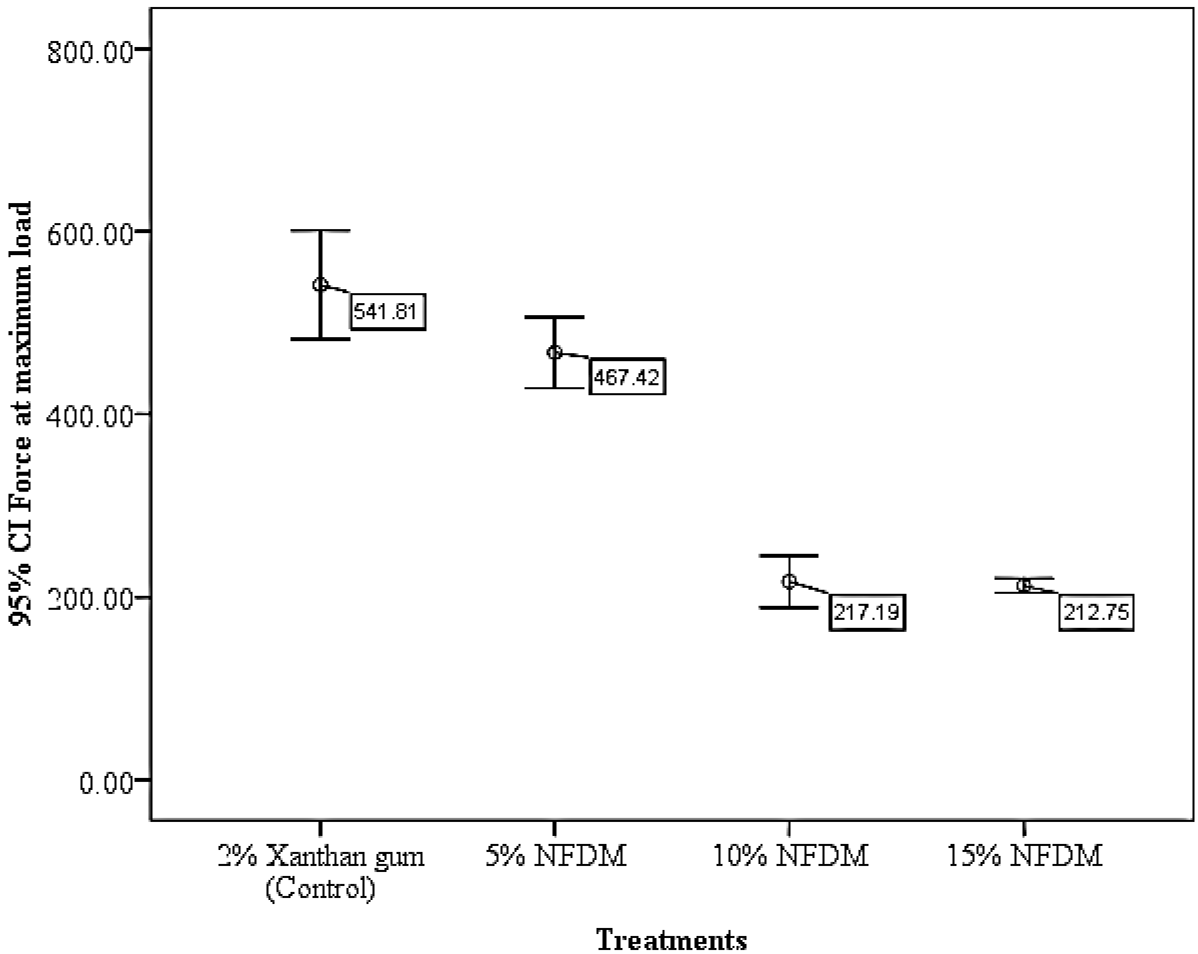

Figure 32. Effect of NFDM (5-15%) on the Force at maximum (mN) exerted on Gluten-Free dough containing 2% xanthan gum

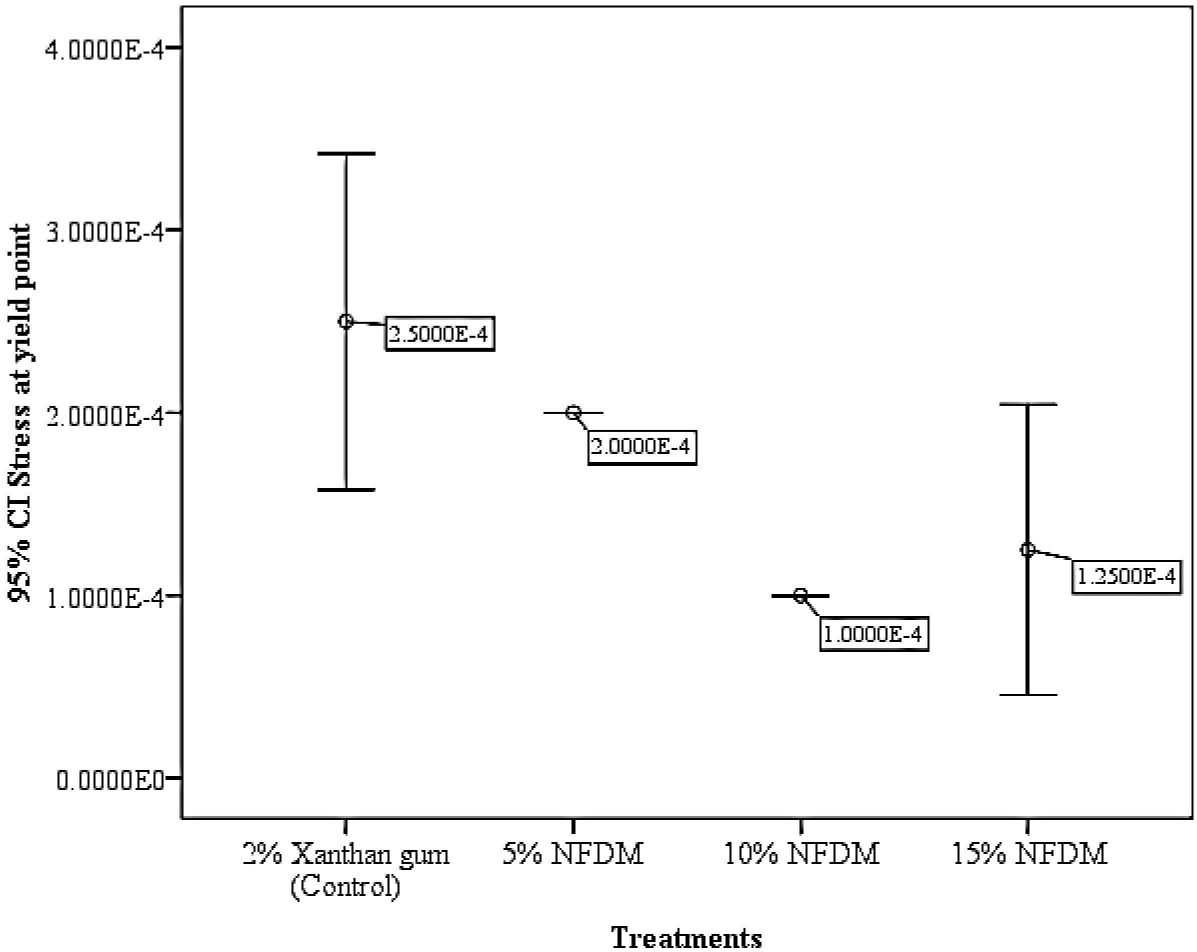

Figure 33. Effect of NFDM (5-15%) on the stress at yield point (mPa) exerted on Gluten-Free dough containing 2% xanthan gum

Table 15

Mean Puncture Parameter Values of Pizza Dough Treatments With Increasing Levels of NFDM Concentration (5 - 15%; 2% Xanthan Gum Control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

Puncture Parameters	Treatments	Mean	SD
Force at max. load (mN)	2% Xanthan gum (Control)	541.81^{c}	37.33
	5% NFDM	467.42^{b}	24.53
	10% NFDM	217.19^{a}	17.84
	15% NFDM	212.75^{a}	4.95
Stress at yield point (mPa)	2% Xanthan gum (Control)	0.00^{b}	0.00
	5% NFDM	0.00^{b}	0.00
	10% NFDM	0.00^{a}	0.00
	15% NFDM	0.00^{a}	0.00

N=16, n=4, P < 0. 05

Tukey's HSD indicated that increasing levels of NFDM in the dough had a significant effect on reducing the compression force and stress at yield point (Table 15, Figure 32, and 33). Gluten-Free dough with 10% and 15% NFDM had no significant difference in compression force used to rupture the dough and the stress at yield point.

TPA. Addition of NFDM to the GF dough had significant effect (p< 0.05) on the mean TPA characteristics (adhesives, cohesiveness, hardness, springiness, chewiness and gumminess) for the tested treatments (Table 16 and Table 17, Figure 34, 35, 36, 37, 38 and 39).

Table 16

Mean TPA Parameter Values of Pizza Dough Treatments With Increasing Levels of NFDM Concentrations (5 - 15%; 2% Xanthan Gum Control). Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

TPA Parameters	Treatments	Mean	SD
Adhesiveness (mJ)	2% Xanthan (control)	1.21[a]	0.52
	5% DMP	22.13[b]	1.35
	10% DMP	23.05[b]	6.01
	15% DMP	25.42[b]	3.23
Cohesiveness	2% Xanthan (control)	0.14[a]	0.01
	5% DMP	0.38[b]	0.01
	10% DMP	0.53[bc]	0.13
	15% DMP	0.64[c]	0.10
Hardness (N)	2% Xanthan (control)	136.03[c]	11.19
	5% DMP	83.91[b]	0.46
	10% DMP	50.73[a]	2.45
	15% DMP	43.24[a]	0.65

N=12, n=3, $P < 0.05$

Tukey's HSD for the TPA measurements showed that increasing levels of NFDM had the following effects:

Adhesiveness.

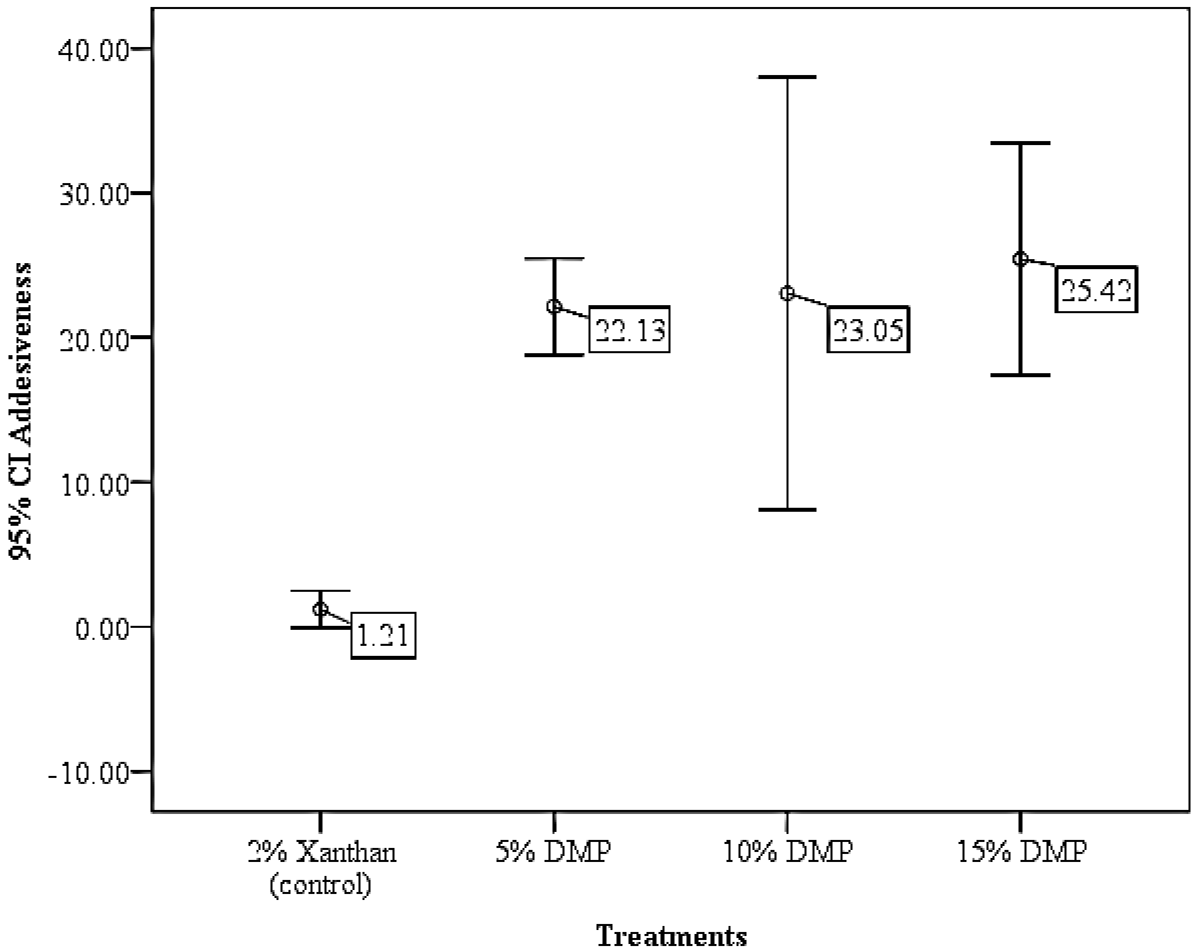

Figure 34. Effect of NFDM (5-15%) on adhesiveness (mJ) of GF dough containing 2% xanthan gum

Addition of NFDM to the GF dough significantly increased adhesiveness. However, GF doughs with 5%, 10% and 15% NFDM were not statistically significant (Table 16 and Figure 34).

Cohesiveness.

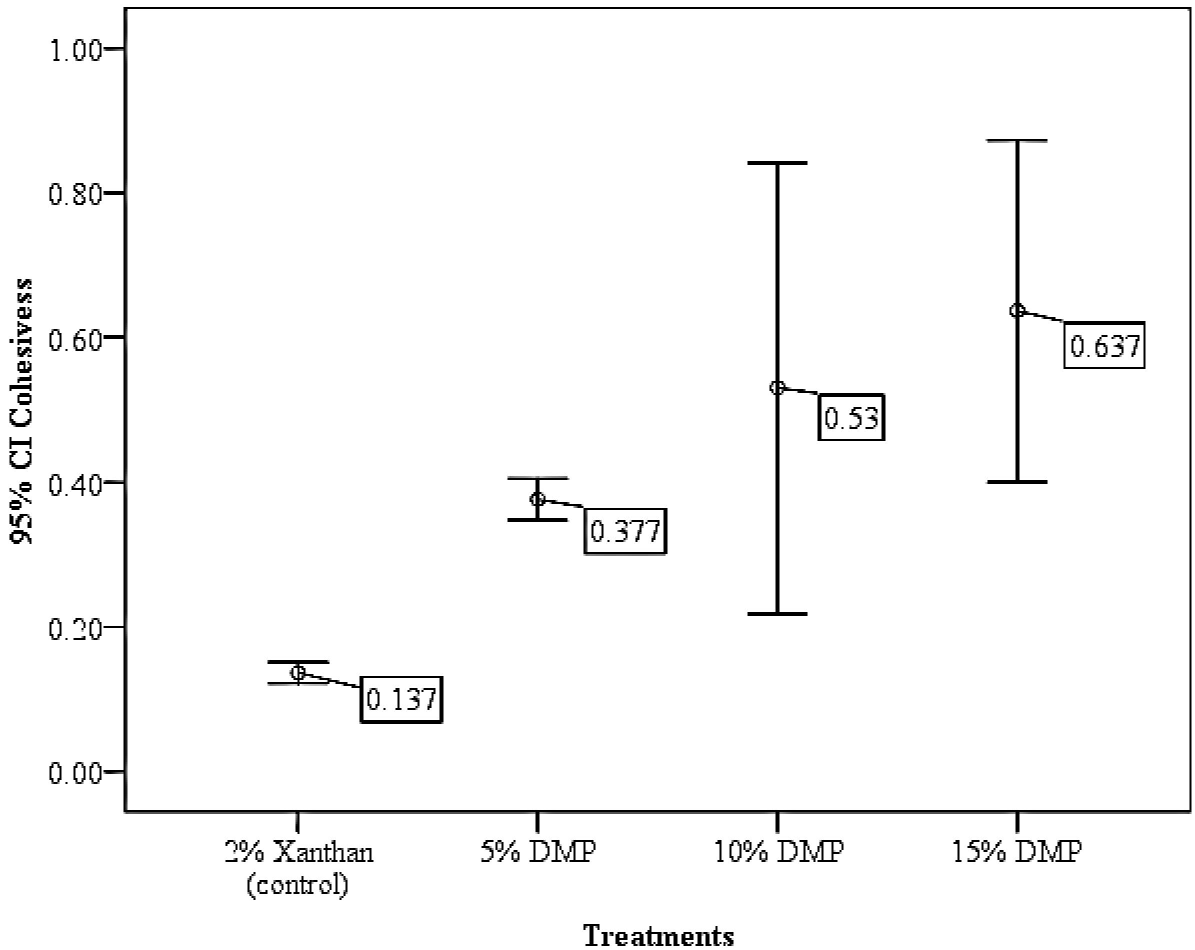

Figure 35. Effect of NFDM (5-15%) on cohesiveness of GF dough containing 2% xanthan gum

Adding NFDM to the GF dough significantly increased cohesiveness. There was no significant difference between 5% and 10% NFDM added dough, and between 10% and 15% NFDM added GF dough (Table 16 and Figure 35).

Hardness.

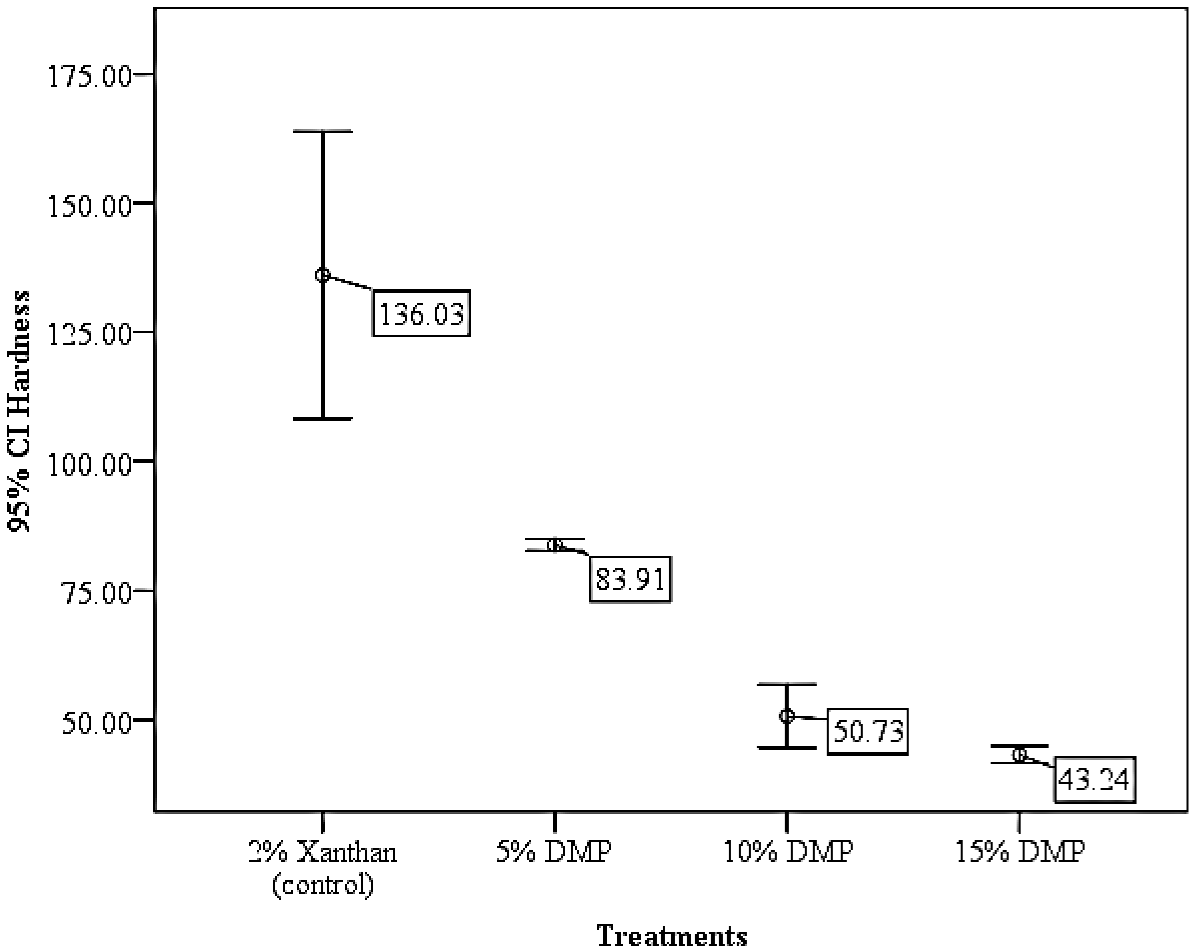

Figure 36. Effect of NFDM (5-15%) on hardness (N) of GF dough containing 2% xanthan gum.

Addition of NFDM to the GF dough significantly decreased hardness. There was no significant difference between 10% and 15% NFDM added GF dough (Table 16 and 36).

Springiness.

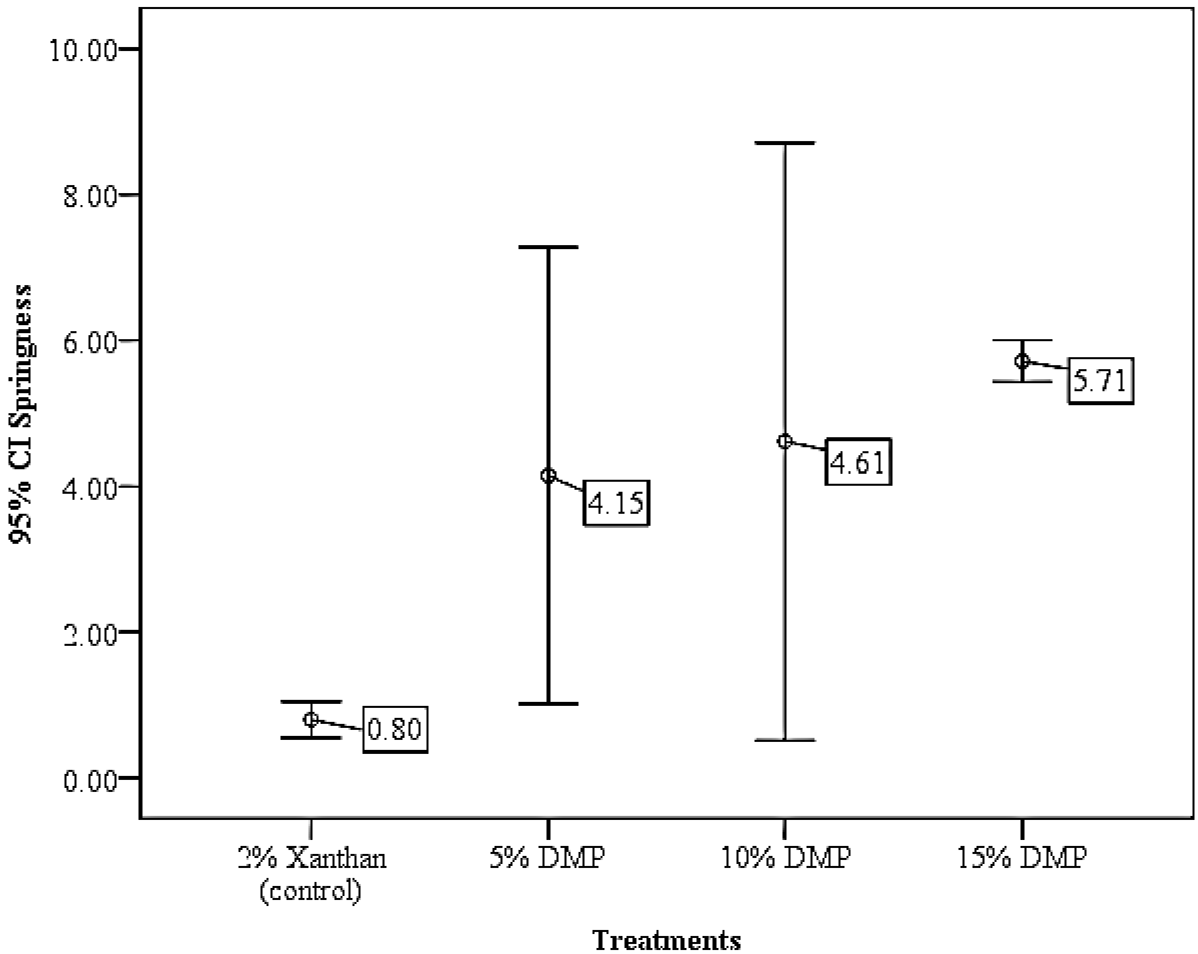

Figure 37. Effect of NFDM (5-15%) on springiness (mm) of GF dough containing 2% xanthan gum

Addition of NFDM significantly increased springiness in the GF dough. However, 5%, 10% and 15% NFDM added dough were not significantly different (Table 17 and Figure 37).

Chewiness.

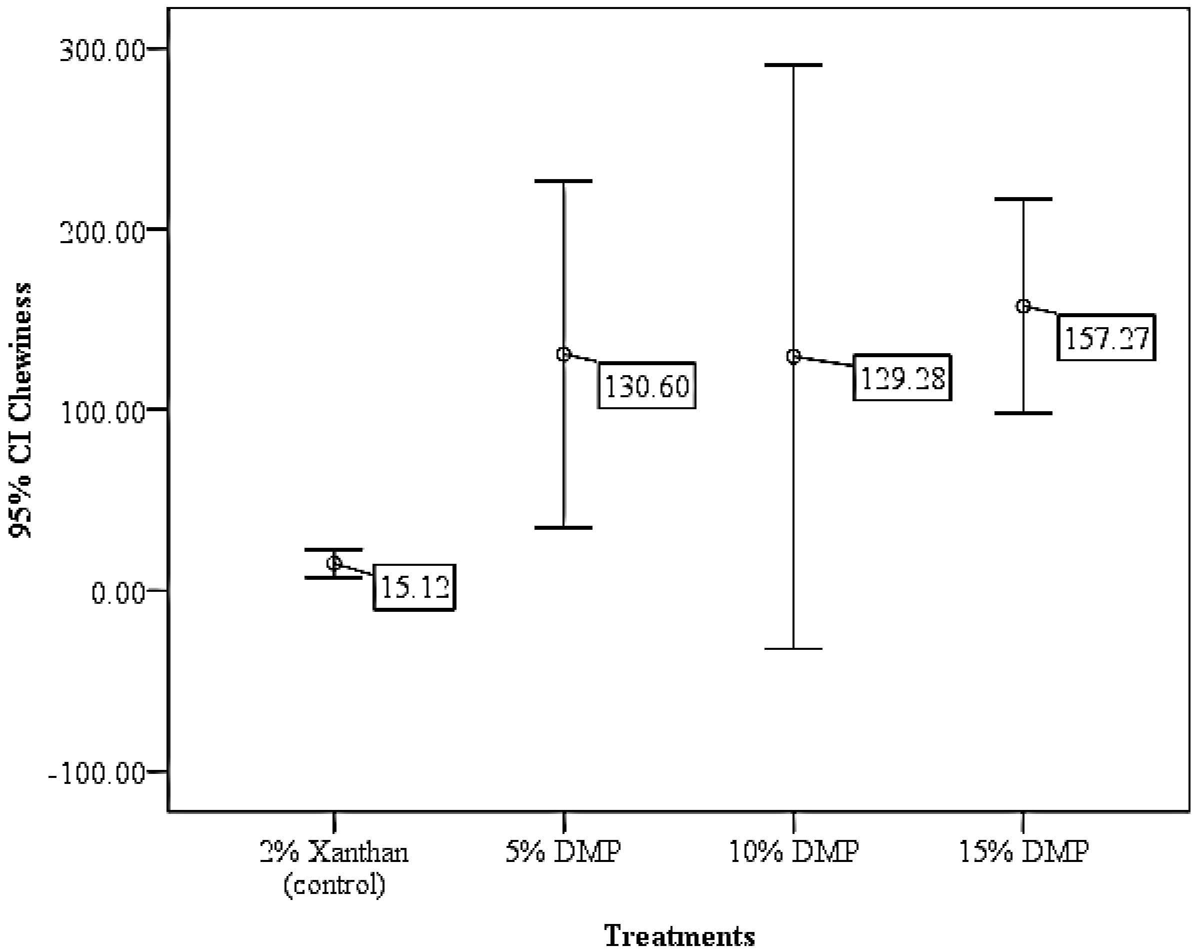

Figure 38. Effect of NFDM (5-15%) on chewiness (mJ) of GF dough containing 2% xanthan gum

Addition of NFDM to the GF dough significantly increased chewiness. However, addition of NFDM to the GF dough beyond 5% did not significantly increase work performed on biting the GF dough (Table 17 and Figure 38).

Table 17

Mean TPA Parameter Values of Pizza Dough Treatments With Increasing Levels of NFDM Concentrations (5 - 15%; 2% Xanthan Gum Control) Continued. Different Superscripts From the Same Parameter are Statistically Significant as Measured Using Tukey's HSD

PTA Parameters	Treatments	Mean	S.D
Springiness (mm)	2% Xanthan gum (control)	0.80^{a}	0.10
	5% DMP	4.15^{b}	1.26
	10% DMP	4.61^{b}	1.65
	15% DMP	5.71^{b}	0.12
Chewiness (mJ)	2% Xanthan gum (control)	15.12^{a}	3.10
	5% DMP	130.60^{b}	38.60
	10% DMP	129.28^{b}	65.00
	15% DMP	157.27^{b}	23.77
Gumminess (N)	2% Xanthan gum (control)	18.86^{a}	2.40
	5% DMP	31.53^{b}	0.92
	10% DMP	26.82^{b}	5.10
	15% DMP	27.48^{b}	3.68

N=12, n=3, P < 0. 05

Gumminess.

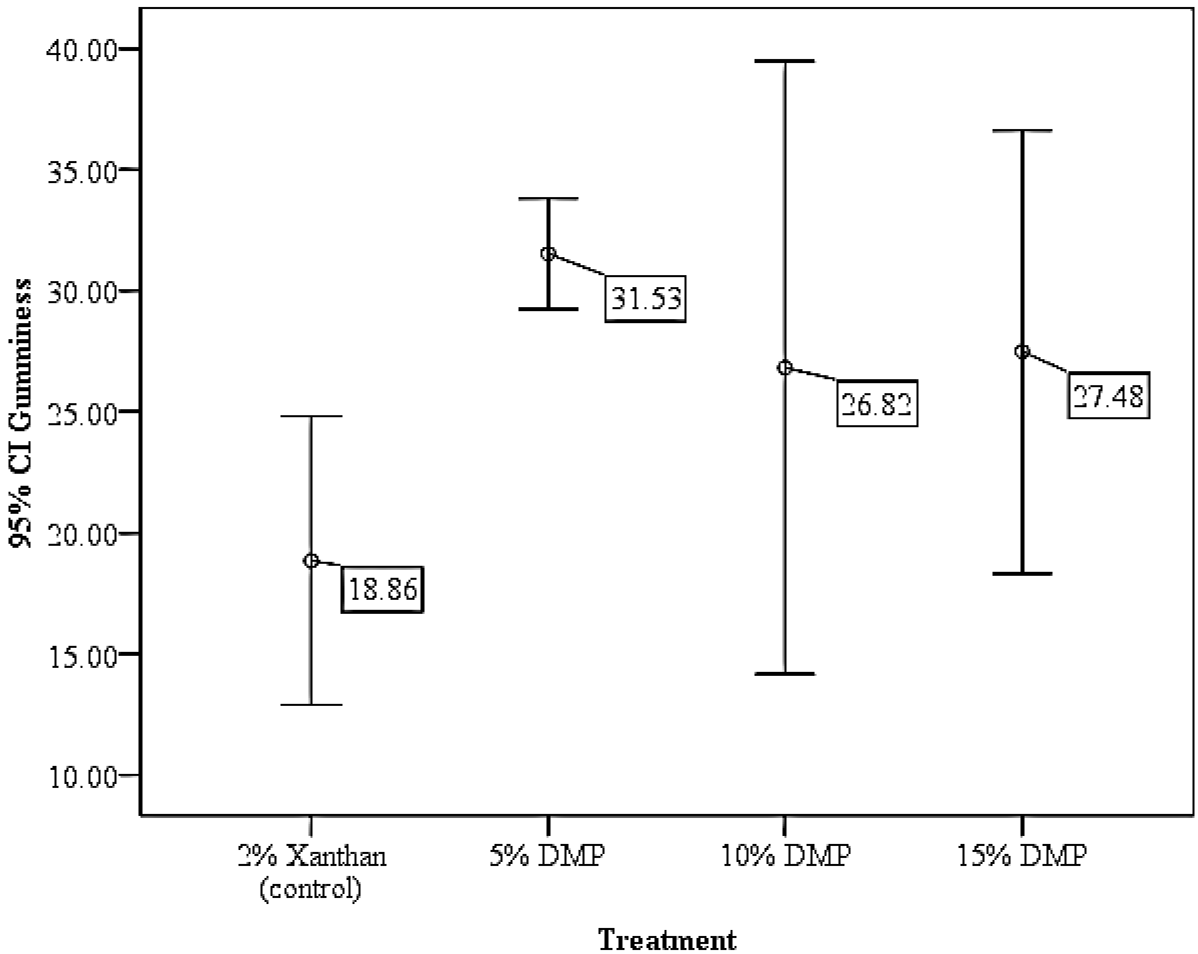

Figure 39. Effect of NFDM (5-15%) on gumminess (N) of GF dough containing 2% xanthan gum

Addition of NFDM significantly increased GF dough gumminess. There was no significant difference between 5%, 10% and 15 NFDM added doughs (Table 17 and Figure 39).

Chapter V: Discussion

Effect of Xanthan Gum Addition on GF Dough Texture Characteristics

The overall quality of a pizza depends on the gluten dough, whose properties are affected by the leavening process, flour type and preparation procedure. For a good quality pizza, the dough has to be sheetable, to rise on proving, hold the gas produced by the yeast, as well as to have good textural and sensory attributes (Gallagher, 2008). Otherwise, pizza crust appearance, taste and texture are critical for consumer identification and acceptance. Other grains and starches lack the mechanism promoting gas retention, flexibility and enhanced water retention (Wieser & Koehler, 2008). In Tables 7, 8, 9 and 10, different levels of xanthan (0 - 5%) gum were applied to the CSC dough to mimic the functionalities of gluten in pizza making with an aim of producing a GF free dough that could be sheetable and extensible.

The parameters obtained were dough elongation force (mN), extension (mm), stress at yield point (mPa), puncture force (mN), adhesiveness (mJ), cohesiveness, hardness (N), springiness (mm), chewiness (mJ) and gumminess (N). All these factors were used to correlate the ability of xanthan gum to replace gluten in pizza crust making.

In Table 7, elongation parameters are reported and they are used as indicators of dough strength (force used to pull the dough strips apart at maximum load) and extensibility without breaking (extension length at maximum load). It can be seen that increasing the level of xanthan gum increased elongation force, extension length and stress at yield point. This was expected since hydrocolloids especially xanthan gum has been reported to be elastic and resistant to deformation (Lazaridou et al., 2007). In Lazaridou's study, the elasticity and resistance to deformation of the hydrocolloids followed the order of xanthan > CMC > pectin > agarose > oat β – glucan. Therefore, the increase in the elongation parameters in this study could be attributed to the concentration effect of xanthan gum in the CSC dough. The dough extension had a xanthan gum concentration threshold (2%) beyond which the increase in length was not significant. Also, it can be observed from this study that xanthan gum is a dough strengthener. Compared to wheat flour dough (elongation force = 697.47 ± 20.53 mN), 2% xanthan gum correlated well but was tougher with elongation force 1566.43 ± 40.39 mN. In a preliminary study, when the dough containing xanthan gum (0-5%) were rolled to sheets, 2% xanthan gum CSC dough was found to be easy to work with (not too loose to work with neither too hard) and gave an optimum rise upon baking.

From Table 8, the puncture parameters are indicative of the dough toughness and resistance to compressive force. This method was used to investigate whether xanthan gum could give strength to CSC pizza crust during processing and last stage of applying toppings before baking. Increasing xanthan gum levels (0-5%) increased puncture force and stress at yield point. As pointed out earlier, this indicated that xanthan gum is not only resistant to pulling force but also compressive force. Therefore, this test correlated with elongation test giving 2% xanthan gum as the optimum concentration for CSC pizza crust making. Similar concentrations have been employed in industrial applications where xanthan gum is widely used for its rheological properties that allow the formation of viscous solutions at low concentrations (0.05 – 2%) and a wide range of pH and temperature (Silva et al., 2009; Ben Salah et al., 2009). However, in this study low concentration below 2% (puncture forces 216.29± 28.47 mN and 401.01 ± 29.83 mN) produced batter like dough which were softer than the wheat control (puncture force 412.62 ± 43.25 mN) and were easily torn by the puncture probe.

In Table 9 and 10, TPA parameters are reported and they are indicative of dough textural changes with different xanthan gum levels. The TPA methodology gives correlations with organoleptic analysis (Bourne, 2002). In this study raw dough was used and sensory analysis was not included. In order to better describe eating action by humans TPA as presented by Peleg (1976) performs two bites; every bite comprise of compression and decompression cycles. Addition of xanthan gum to the CSC dough had no effect to adhesiveness, this is important because less adhesive dough is easy to work with during sheeting. This observation disagrees with findings by Ghodke (2009) who reported that increasing guar gum concentration in wheat dough increased stickiness by absorbing water necessary for gluten cross linking. Also, Cohesiveness increased with increase in xanthan gum concentration which could be explained by the behavior (swelling) of xanthan gum upon hydration (Kulp et al., 1974; Lopez et al., 2001; Nishita et al., 1976). Cohesiveness and hardness better illustrated that the dough toughened with increase in xanthan gum and this correlated with the other parameters (springiness, gumminess and chewiness). Compared to wheat flour dough, 2% xanthan gum had closer similarities to those of wheat dough. This confirms to studies by Lazaridou et al. (2007).

Overall, elongation methodology, puncture test and TPA methodology had a correlation in determining the CSC dough textural characteristics during handling and processing. Two percent (2%) xanthan gum performed optimum with an easy to work with texture in terms of sheetability and extensibility.

Effect of Dairy Ingredients Addition on GF Dough Texture Characteristics

After selection of 2% xanthan gum CSC pizza dough as the optimum, it was treated with dairy ingredients (whey protein and NFDM) and analyzed for textural changes. This was intended to add functional benefits and nutritional properties to the CSC pizza crust.

When incorporated into GF breads, dairy ingredients improve overall shape and volume, and a firmer crumb structure (Gallagher et al., 2003). They give appealing dark crust and white crumb to the breads and receive good acceptability in sensory tests (Gallagher et al., 2003). It was with this assumption that these benefits could be transferred to the baked CSC pizza crust that the authors of this dissertation chose to use these dairy ingredients. Also, it was assumed that the effects of other proteins were minimal and that only whey protein and NFDM had main effects on the CSC dough texture.

Effect of Whey Protein Addition on GF Dough Texture Characteristics

Whey protein creates and stabilizes air bubbles in a liquid and has good foaming capacity (Renner & Abdi El-Salam, 1991). This is important in creation of air bubble nuclei during baking that aids in rising of bread and in our case GF pizza crust. Acid whey powder improves the crust color (golden surface) and enhances flavor in dairy products (Kosikowski, 1979). These characteristics are assumed to be transferred to the final baked product.

In Tables 11, 12 and 13, different levels of whey protein (1-3%) were applied to the 2% xanthan gum CSC dough to investigate their effect on the dough sheetability and extensibility. Same parameters as in the effect of xanthan gum were evaluated and had striking revelations.

From Table 11, the elongation parameters indicated that increasing whey proteins led to subsequent reduction in elongation force and stress at yield point. This is due to the softening effect of whey protein to the GF dough which could be attributed to competition for hydration water with xanthan gum. Hudson et al. (2000) observed that upon heating whey proteins unfolds and aggregates and are capable of binding large amounts of water depending on the pH, ionic strength and thermal conditions. In this study, heat could have been from the water used during mixing of the dough in the Hobart mixer, the temperature of the water was not controlled. Also, increasing whey proteins resulted to increase extension at maximum load which could be attributed to increase in protein network (Kenny et al., 2001). Gillies (1974) reported that whey acts as a tenderizer in those foods where a soft and tender structure is desired. In terms of performance, 3% whey protein GF dough was softest and stretched most (778.86 ± 57.37mN and 19.06 ± 1.37mm, mean elongation force and mean extension at maximum load respectively) but was hard to work with while 1% and 2% whey GF dough had the same performance. Two percent (2%) whey protein was chosen as optimum based on preliminary study sensory attributes by the authors (not reported).

From Table 12, data indicated that a threshold concentration of whey protein existed beyond which increasing the levels of whey in the CSC GF dough increased the compressive force. The same observation was seen from data on hardness (Table 13). This was desired since the increase in resistance to compressive deformation ensured non-compromise to the handling ability of dough during processing and holding of toppings. However, this behavior of whey protein and xanthan gum could not be explained as the study design was not set to detect interaction effects. As in elongation parameter, 2% whey performed optimum in resisting compressive deformation and correlated to a better golden and risen CSC pizza crust in a preliminary baking study.

From Table 13, TPA parameters were used and they correlated with both elongation and puncture tests. Adhesiveness increased with increase in whey protein concentration and this could be attributed to high absorption of water resulting to less-network of the CSC flour components that become sticky. Ghodke (2009) reported that water absorption was generally accepted to be of main importance in dough stickiness and the higher the water absorption the more sticky dough it gives. Regardless, 2% whey CSC GF dough had stickiness that was not significantly different from that of the control (2% xanthan gum). Cohesiveness, hardness and gumminess correlated with the data from Tables 11 and 12, with 2% whey protein as the concentration of choice with good performance and less sticky on rolling.

Effect of NFDM Addition on GF Dough Texture Characteristics

Nonfat dry milk like other dairy ingredients is used to increase nutritional, organoleptic and functional properties to dairy products (Eedogdu-Arnoczky et al., 1996). In this study, textural changes of the CSC dough with various levels of NFDM were evaluated to investigate its performance on handling and processing (rolling and sheeting).

Tables 14, 15, 16 and 17 are indicative of 2% CSC dough response to deformation with increase in the levels of NFDM (5-15%). The response was similar to whey protein with slight differences which are discussed below.

From Table 14, data indicated that increasing NFDM concentration in the 2% CSC dough decreased elongation force and stress at break point. This suggests that NFDM like whey proteins are dough softeners. This softening behavior can be attributed to the formation of a continuous NFDM protein network in the dough that makes the dough soft (Gillies, 1974). On the other hand, increasing NFDM in the GF dough increased the extension length of the GF dough upon stretching. This conformed to observations made in a study by Kenny et al. (2001). In all the elongation parameters evaluated, increasing the concentration of NFDM beyond 10% had no significant effect. Dough with 5% NFDM performed better on handling and processing with substantial strength to deformation and good baking behavior.

From Table 15, puncture parameters correlated with elongation data; the dough resistance to both pulling and compressive deformation reduced with increase in NFDM concentration. However, 5% NFDM (puncture force at maximum load = 467.42 ± 24.53 mN) dough resistance to puncture was close to the control (puncture force at maximum load = 541.81 ± 37.33 mN).

The softening behavior of NFDM was strikingly different compared to whey proteins that at a threshold concentration puncture force increased with increase in whey. The reduced resistance to puncture force could be speculated to result from extensive absorption of water by NFDM resulting to a soft proteinous matrix that is not stiff enough to resist compressive force. Use of NFDM was found to increase water absorption as reported by Dubois and Dreese (1984).

In Table 16 and 17, data for TPA parameters correlated with findings on Tables 14 and 15. Addition of NFDM reduced hardness similar to Table 15 and this could be attributed to NFDM hydration behavior (Dubois & Dreese, 1984). On the other hand, addition of NFDM increased cohesiveness, springiness, chewiness, and gumminess. These parameter values suggested that 5% was optimum in handling and processing performance because beyond 5% most of the treatment effects were not significant.

Chapter VI: Conclusions and Recommendations

The study revealed that sheetable GF pizza crusts could be made from a cassava, sorghum and chickpea composite flour by adding 2% xanthan gum and dairy ingredients (either 2% whey or 5% NFDM) to improve textural characteristics of the dough. The GF pizza crusts made possessed excellent softness and pliability, resistance to puncture during processing and good elongation length. Further, a detailed study on interaction between xanthan gum and whey proteins is required.

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Appendix A

Exported SPSS raw data for xanthan gum addition TPA

Factor	Adhesiveness	cohesiveness	Hardness	springiness	Chewiness	Gumminess
1	2.45	0.29	64.5	1.30	24.13	18.56
1	1.22	0.27	61.11	1.10	18.44	16.76
1	3.39	0.30	58.84	1.50	26.65	17.77
2	0.20	0.08	69.74	0.40	2.28	5.69
2	0.18	0.08	67.85	0.40	2.10	5.26
2	0.14	0.08	69.85	0.30	1.70	5.67
3	0.88	0.05	126.56	0.70	4.58	6.55
3	0.94	0.05	119.92	0.90	5.70	6.33
3	0.91	0.05	122.86	0.80	5.15	6.44
4	1.22	0.14	140.29	0.70	13.77	19.66
4	0.68	0.13	123.33	0.80	12.93	16.16
4	1.72	0.14	144.46	0.90	18.67	20.75
5	0.02	0.14	197.09	0.70	18.83	26.90
5	0.01	0.16	203.62	0.80	26.03	32.53
5	0.02	0.13	180.99	0.70	16.67	23.81
6	0.40	0.19	292.45	1.84	103.87	56.45
6	0.24	0.17	300.75	1.83	94.65	51.72
6	0.01	0.19	311.53	2.00	117.60	58.80

Note: These are averages, number of times a factor appears represents replications. 1 = wheat flour, 2 = 0% xanthan, 3 = 1% xanthan, 4 = 2% xanthan, 5 = 3% xanthan and 6 = 5% xanthan.

Exported SPSS raw data for xanthan gum addition Puncture test

Factor	Maximum load	Stress at yield point
1	347.42	0.0001
1	402.22	0
1	409.52	0
1	449.21	0
1	454.74	0
2	196.55	0.0001
2	197.30	0.0001
2	206.66	0.0001
2	215.66	0.0001
2	265.26	0.0001
3	366.52	0.0002
3	386.31	0.0002
3	391.13	0.0002
3	418.03	0.0002
3	443.04	0.0002
4	511.35	0.0002
4	519.09	0.0002
4	540.81	0.0003
4	542.67	0.0003
4	594.12	0.0003
5	876.61	0.0004

5	878.61	0.0004
5	901.37	0.0004
5	915.03	0.0004
5	934.26	0.0004
6	2162.90	0.0010
6	2163.11	0.0010
6	2210.92	0.0010
6	2465.47	0.0012
6	2513.67	0.0012

Note: These are averages and the number of times a factor appears represents replications. 1 = wheat flour, 2 = 0% xanthan, 3 = 1% xanthan, 4 = 2% xanthan, 5 = 3% xanthan and 6 = 5% xanthan.

Exported SPSS raw data for xanthan gum addition Elongation test

Factor	Maximum load	Extension at maximum loan	Stress at yield point
1	721.01	68.38	0
1	683.27	54.83	0
1	688.14	71.81	0
2	526.88	2.26	0.006
2	559.32	1.77	0.006
2	558.44	1.73	0.006
3	731.37	4.16	0.008
3	710.54	4.61	0.008
3	857.70	5.27	0.009
4	1610.81	9.99	0.017
4	1556.64	8.28	0.017
4	1531.84	10.56	0.017
5	2393.94	12.27	0.026
5	2016.00	10.66	0.022
5	2252.00	12.82	0.024
6	2670.99	10.78	0.029
6	2590.87	9.65	0.0281
6	2753.52	10.40	0.0299

Note: The number of times a factor appears represents replications. 1 = wheat flour, 2 = 0% xanthan, 3 = 1% xanthan, 4 = 2% xanthan, 5 = 3% xanthan and 6 = 5% xanthan.

Appendix B

Exported SPSS raw data for whey protein addition TPA

Factor	Adhesiveness	cohesiveness	Hardness	springiness	Chewiness	Gumminess
1	1.22	0.14	140.29	0.70	13.77	19.66
1	0.68	0.13	123.33	0.80	12.93	16.16
1	1.72	0.14	144.46	0.90	18.67	20.75
2	1.46	0.15	106.29	1.38	22.51	16.31
2	1.82	0.13	107.95	1.08	15.08	13.96
2	1.49	0.12	101.57	0.88	10.67	12.13
3	1.31	0.11	129.61	0.78	11.38	14.58
3	1.13	0.11	135.28	1.38	21.03	15.24
3	0.86	0.11	140.67	0.78	12.00	15.38
4	9.80	0.17	133.10	1.18	27.19	23.04
4	8.53	0.14	158.22	1.18	27.05	22.93
4	7.35	0.15	143.27	1.08	23.28	21.56

Note: These are averages and the number of times a factor appears represents replications. 1 = 2% xanthan gum, 2 = 1% whey, 3 = 2% whey, and 4 = 3% whey.

Exported SPSS raw data for whey protein addition elongation test

Factor	Maximum load	Extension at maximum loan	Stress at yield point
1	1610.81	9.99	0.0175
1	1556.64	8.28	0.0169
1	1531.84	10.56	0.0166
2	1183.84	14.37	0.013
2	1118.90	14.82	0.012
2	1206.24	14.72	0.012
3	1140.89	15.41	0.012
3	1134.11	15.71	0.012
3	1164.59	15.06	0.011
4	812.59	17.70	0.009
4	810.97	20.44	0.009
4	712.42	19.04	0.008

Note: These are averages and the number of times a factor appears represents replications. 1 = 2% xanthan gum, 2 = 1% whey, 3 = 2% whey, and 4 = 3% whey

Exported SPSS raw data for whey protein addition puncture test

Factor	Maximum load	Stress at yield point
1	594.12	0.0003
1	511.35	0.0002
1	542.67	0.0003
1	519.09	0.0002
1	540.81	0.0003
2	468.72	0.0002
2	442.12	0.0002
2	462.39	0.0002
2	462.19	0.0002
2	444.43	0.0002
3	525.62	0.0003
3	574.10	0.0003
3	562.58	0.0003
3	525.98	0.0003
3	506.55	0.0002
4	655.51	0.0003
4	679.69	0.0003
4	713.60	0.0003
4	697.84	0.0003
4	686.66	0.0003

Note: These are averages and the number of times a factor appears represents replications. 1 = 2% xanthan gum, 2 = 1% whey, 3 = 2% whey, and 4 = 3% whey.

Appendix C

Exported SPSS raw data for NFDM addition TPA.

Factor	Adhesiveness	cohesiveness	Hardness	springiness	Chewiness	Gumminess
1	1.22	0.14	140.29	0.70	13.77	19.66
1	0.68	0.13	123.33	0.80	12.93	16.16
1	1.72	0.14	144.46	0.90	18.67	20.75
2	23.36	0.37	84.15	5.48	169.65	30.96
2	22.33	0.39	83.38	3.98	129.70	32.59
2	20.69	0.37	84.20	2.98	92.46	31.03
3	28.60	0.65	48.09	5.98	187.76	31.40
3	16.66	0.40	52.93	2.78	59.30	21.33
3	23.89	0.54	51.16	5.08	140.79	27.72
4	26.62	0.64	43.58	5.78	161.13	27.88
4	27.87	0.73	42.49	5.78	178.87	30.95
4	21.76	0.54	43.65	5.58	131.81	23.62

Note: These are averages and the number of times a factor appears represents replications. 1 = 2% xanthan gum, 2 = 5% NFDM, 3 = 10% NFDM, and 4 = 15% NFDM.

Exported SPSS raw data for NFDM addition puncture test

Factor	Maximum load	Stress at yield point
1	594.12	0.0003
1	511.35	0.0002
1	542.67	0.0003
1	519.09	0.0002
2	434.12	0.0002
2	493.16	0.0002
2	469.61	0.0002
2	472.78	0.0002
3	201.91	0.0001
3	234.86	0.0001
3	201.74	0.0001
3	230.26	0.0001
4	212.14	0.0001
4	216.94	0.0001
4	206.00	0.0001
4	215.90	0.0002

Note: These are averages and the number of times a factor appears represents replications.

1 = 2% xanthan gum, 2 = 5% NFDM, 3 = 10% NFDM, and 4 = 15% NFDM.

Exported SPSS raw data for NFDM addition elongation test

Factor	Maximum load	Extension at maximum loan	Stress at yield point
1	1610.81	9.99	0.0175
1	1556.64	8.28	0.0169
1	1531.84	10.56	0.0166
2	1047.83	20.66	0.011
2	1054.25	16.55	0.011
2	1330.28	19.06	0.014
3	489.57	15.24	0.0053
3	496.82	14.02	0.0054
3	513.57	15.93	0.0056
4	410.00	14.90	0.004
4	400.75	12.33	0.004
4	416.86	16.12	0.005

Note: These are averages and the number of times a factor appears represents replications. 1 = 2% xanthan gum, 2 = 5% NFDM, 3 = 10% NFDM, and 4 = 15% NFDM.