GLUTOGRAPH ‘E’: A SIMPLE RHEOMETER TO MEASURE QUALITY OF COOKED PASTA

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GLUTOGRAPH 'E': A SIMPLE RHEOMETER TO MEASURE

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

MASTER OF SCIENCE

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ABSTRACT

Glutograph 'E' was designed to determine the stretch and relaxation properties of wet gluten. Usage of this equipment to evaluate the cooked pasta texture has not been reported and thus is the goal of this research. Procedure development involved the evaluation of the number of impulses, relaxation time, the number of spaghetti strands, and the number of tests per sample to give a reliable treatment mean. Different impulses settings affected the magnitude of strain, time and percent recovery. Traditional spaghetti required less time to reach 800 B.U and had greater percent recovery and strain values than did nontraditional spaghetti. Glutograph results were compared with firmness results obtained using a texture analyzer (TA-XT2) with a Pasta blade or with a Modified Ottawa cell. Compression type probe parameters were positively correlated to glutograph stretch time. Glutograph E can be used as potential equipment to detect differences in texture of cooked pasta.

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INTRODUCTION

Four quality factors often associated with foods are appearance (size, color and shape), flavor (taste and smell), texture (touch and sound) and nutrition (carbohydrates, protein, fat minerals and vitamins). Texture is considered to be the least researched factor among the four (Haraldsson, 2010). Texture is a sensory attribute that often is taken for granted. Consumers usually do not comment on the texture attribute unless it deviates greatly from the expectation.

Primary textural properties that are associated with cooked pasta are firmness, elasticity, and surface integrity and stickiness. These textural properties can be measured by sensory evaluation or by instrumental methods (Sissons et al., 2008). Both methods have their own distinct advantages and thus must be carefully standardized to produce meaningful and reproducible results.

Methods for analyzing texture of pasta have long been developed and significant progress has been observed over the years (Edwards et al., 1993; Manthey and Dick, 2012). AACC International Approved Method 66-50 (Pasta and Noodle Cooking Quality – Firmness) is the standard procedure for measuring cooking quality of long-goods such as spaghetti. This procedure uses the Pasta blade attached to a texture analyzer and measures the work required to cut through a strand of spaghetti. Pasta containing nontraditional ingredients may not be adequately tested by using the Pasta blade probe (Manthey and Dick, 2012). Pasta blade measures only a small area of cooked spaghetti, since the blade is only 1 mm wide. Uniformity of ingredient distribution and physical properties of ingredient can affect firmness results and add to variability of results. Another limitation of Pasta blade attachment is that it only provides information on cooked firmness and not other textural attributes.

Texture Profile Analysis (TPA) test is a compression test that was developed by General Foods Corporation in 1978. TPA can measure a number of parameters and is typically used for noodles and pasta texture analysis (Rosenthal, 1999). Spaghetti strands are compressed twice and analysis of the force-time curve obtained gives information about the flexibility and extensibility, cohesiveness, stickiness, adhesiveness, springiness, chewiness and gumminess.

A compression-extrusion test has been developed using the Ottawa cell or modified Ottawa cell (Manthey and Dick, 2012). Modified Ottawa Texture Measuring System compresses and extrudes cooked pasta through a grid of holes drilled through the aluminum base plate. Although this cell has a shallow sample base, it is adequate for pasta products. It has round sample space and plunger. The dimension of the base is 78 mm (diameter) and consists of 61 holes (5mm diameter) in 5 concentric circles. The hole-to-sample area ratio is 25.1%. The pasta sample is compressed-extruded by the action of a plunger, whose base is made from aluminum or Plexiglas. The pasta is compressed twice similar to that of the TPA.

Glutograph is a simple rheometer that is built by Brabender (Glutograph-E, Brabender GmBH and Co. Duisburg, Germany, 2010) to determine the stretch and relaxation values of washed wet gluten for wheat (Rosenthal, 1999; Alamri et al., 2009). The glutograph consists of two parallel, round and corrugated plates that are mounted at a specified distance opposite to each other. A sample is placed in between these two corrugated plates and while the upper plate remains still, the lower plate turns with a constant force. The magnitude of the stretching and deflection depends on the gluten quality. Results obtained from the glutograph can be explained using the creep and recovery method, which analyzes the rate of deformation (measured as a function of time and applied stress) and recovery (elasticity).

Beyond texture measurements of large deformation by texture analyzers, limited information is available pertaining to the use of other equipment to determine the texture of cooked pasta. Therefore, the objective in this paper was to utilize the glutograph machine, a less used rheological instrument, to analyze the texture of cooked pasta and then compare results to more commonly used applications involving texture analyzers fitted with a Pasta blade or a Modified Ottawa cell.

LITERATURE REVIEW

Traditional Ingredients in Pasta

Durum wheat (*Triticum turgidum* var. durum) is the best type of hard wheat for the production of spaghetti, macaroni and other pasta products due to the high content of protein and carotenoid pigment, lutein, which gives pasta the bright yellow color desired by consumers. The most important factor in producing high quality pasta is protein (gluten) content. It is crucial that semolina protein content is above 12% to ensure highest quality of pasta (Sissons, 2008).

Semolina protein content and composition affect dough strength. Gluten is a protein matrix composed of glutenin and gliadin storage proteins. Glutenins are considered the major contributor to the elasticity of dough, whereas gliadins are responsible for cohesiveness and conferring viscosity (Edwards et al., 2003). Gliadins are composed of monomeric polypeptides and glutenins consist of polymers of subunits that are linked by intermolecular disulfide bonds.

Gluten is formed when wheat flour is mixed with water to form dough and it has visco-elastic property (Peressini et al., 2000). Gluten strength is a term typically used to describe the ability of proteins to form desired network that affects the cooking quality of pasta. Strong gluten wheat results in a less sticky dough and better cooked firmness and cooking stability; whereas, rapid deterioration and soft texture is associated with weak gluten (Sissons, 2008). Durum wheat cultivars that have strong gluten and low protein content do not always produce better pasta cooking quality as compared to those cultivars that have high protein content and gluten of conventional strength (Haraldsson, 2010). High protein semolina produced pasta with increased firmness and reduced cooking loss (Sissons, 2008). Low protein content in semolina results in less intensive gluten matrix from which starch granules can swell and amylose can leach and contribute to increased cooking loss.

Nontraditional Ingredients in Pasta

The physical and textural attributes in finished goods of pasta made using different grains have been studied (Marconi and Carcea, 2001). One of the studies conducted used spaghetti that was prepared from durum wheat supplemented with soy flour to increase protein content rich in lysine (Shogren et al., 2006). Bahnassey and Khan (1986) evaluated edible legumes (roasted navy, pinto and lentil flours) in their spaghetti sample preparations to increase the protein content. The authors found that adding legume flours and protein concentrate into semolina resulted in higher intensity of cracking and shattering compared to the control (made with 100% semolina). Also, the cooked firmness values were greater for legume fortified spaghetti samples than the control spaghetti.

Pasta manufacturers have increased production of whole wheat pasta in response to increased consumer demand. Bran and germ, which are typically the by-products of milling, are included in whole wheat semolina. Pasta made from whole wheat flour provides multiple healthful phytochemicals such as greater amount of vitamins, minerals, antioxidant and dietary fiber compared to pasta made from semolina (Hirawan et al., 2009). Although bran and wheat germ are usually the by-products from the milling process, they contain considerable amount of nutrients that can be beneficial. These by-products from the milling can be re-introduced into pasta processing to enhance its nutritional contents (Hirawan et al., 2009).

Pasta that is made using whole grain must contain all the essential parts and naturally-occurring nutrients of the entire seed without altering their original proportions and their content should be kept the same, as the original, even after processing. In other words, the bran, germ and endosperm must be present in their natural ratio to be certified as a whole grain product (Whole Grains Council, 2013). Whole grain that is used to make pasta is reported to be excellent source of fiber, minerals (iron and magnesium) and phytochemicals (phenolic compounds and carotenoids) (Whole Grains Council, 2013). Whole grain and whole wheat pastas typically exhibit a dark color, with a rough and heavy texture and can have slightly unpleasant off-flavors (Manthey and Schorno, 2002; West, 2012).

Pasta Production

Nowadays, pasta production uses continuous, high capacity extruders that operate with the auger extrusion principle. In this extrusion process, kneading and extrusion are carried out in a single operation. There are a couple of steps involved in making pasta: ingredient mixing, ingredient hydration, dough development, extrusion, and drying. Dough development involves kneading hydrated semolina into dough. During ingredient hydration and dough development, the storage proteins change their conformation, which results in sulfhydryl groups on the protein to become sterically available for reaction (Marchylo et al., 2004). The sulfhydryl groups form disulfide bonds between proteins that ultimately results in a matrix that encapsulates starch granules.

In the extrusion barrel, dough is kneaded into a homogenous mass that is forced through a die that determines the shape of the pasta. Temperature of the dough is maintained between 40 and 45 °C during extrusion to prevent damage to the gluten matrix (Marchylo et al., 2004). During the extrusion process, it is critical to maintain a uniform flow rate throughout. Variation in flow rate could cause the dough being forced through the die at different rates and pressure, and result in non-uniform size and shape.

Drying is considered the most difficult step to control during pasta manufacturing. This step reduces the moisture content of pasta from approximately 31% to 12% and by doing so retains the shape of the finished product and extends its shelf life. Low temperature drying (≤50

°C) has been applied to pasta for the longest time to obtain microbial and physicochemical stability. High temperature drying (≥70 °C) and ultrahigh temperature drying (≥90 °C) are used more often by the pasta manufacturers due to shorter drying time and improvement in the textural characteristics of pasta products (Cuq et al., 2003).

Low temperature drying initiates less organized protein network and causes no significant modifications detected to the inner structure of starch granules (Noni et al., 2010). Cooking quality is associated with protein content and gluten properties upon low temperature drying. However, when high temperature drying with low moisture (<15%) was applied, complete coagulation of protein that enhances the formation of protein network occurred (Noni et al., 2010). Pasta quality was greatly impacted due to high breakages observed in protein fibrils when gluten quality was poor and low in quantity.

Mechanical properties of pasta transformed drastically during the drying process from soft product (i.e., fresh pasta) into a rigid product (i.e., dry pasta). Due to the changes in mechanical properties of pasta, they caused internal stress during drying. Pasta transformed from plastic behavior (above 39% water db) to elastic behavior (below 23% water db), with an intermediate plasto-elastic behavior (Cuq et al., 2003). Not only that, high temperature drying is also associated with better preservation of protein network and reduced swelling of starch (Scott and Hui, 2004). High temperature drying is preferred in the pasta industry because it promotes good pasta cooking quality by increasing the firmness of cooked pasta and reducing the undesirable stickiness property (Zweifel et al., 2003). Pasta manufacturers would be able to utilize low protein durum wheat to produce pasta with good cooking quality by applying high temperature drying. When high temperature drying is utilized, denaturation of protein occurs that helps prevent the starch granules from rupturing during the cooking process. Discoloration of pasta can occur when dried at ultrahigh temperature. Ultrahigh temperature drying often increases the browning of pasta (due to Maillard browning reaction).

Protein/Starch Interactions

Starch (74-76% db) is the major component found in semolina and gelatinized starch attributes affect the firmness of cooked spaghetti (Petitot et al., 2009). Starch granules can be further classified into two groups depending on their size distribution. Amylose is a linear polysaccharide chain consists up to 5,000 glucose units linked together by α-1,4-glycosidic bonds. Amylopectin is a highly branched chain which can contains up to one million glucose units attached together with α-1,4 and α-1,6 glycosidic bonds (Grzybowski and Donnelly, 1977). The amount of amylose varies in starch (Edwards et al., 2003). Upon introduction of heat, starch granules begin to swell, which disrupts hydrogen bonds and eventually allows amylose molecules to diffuse into surrounding aqueous medium. This process is called starch gelatinization. Starch gelatinization characteristic is influenced by level of water content present.

Durum cultivars of high gluten quality retained their amylopectin to amylose ratio during the cooking process and cooking loss is at its minimum (Sissons, 2008). In contrast, durum that contains poor gluten quality showed greater leaching of amylose upon cooking, which increased the amylopectin to amylose ratio and thus resulted in higher degree of stickiness. During cooking, presence and nature of different zones observed in pasta cross-section suggested that gelatinization occurs in an inward direction. Water penetration is at its highest rate at lower protein levels (Grzybowski and Donnelly, 1977). Depending on the amount of protein present, the rate of starch gelatinization differs (Sissons, 2008).

Semolina protein content generally ranges from 12 to 14%. About 80% of these proteins are storage proteins, gliadin and glutenin. Gliadin, a monomeric protein is bound together through peptide bonds and interchain disulfide bonds. Glutenin is a polymeric protein that can be much larger than gliadin. Glutenin proteins consist of low-molecular weight and high-molecular weight subunits connected through disulfide bridges and cross bonding. Upon contact with water, the disulfide bridges of gliadin and glutenin break and eventually unfold the molecule as shown in Figure 1 (Haraldsson, 2010). Cross-linkage between gliadin and glutenin is formed at the ends of the former disulfide bridges, which strengthen the gluten network and is critical in pasta manufacturing. High temperature drying triggered the increase in the crosslink density of both protein phase and starch granules and thus improved the resistance to breakage (Edwards et al., 2003).

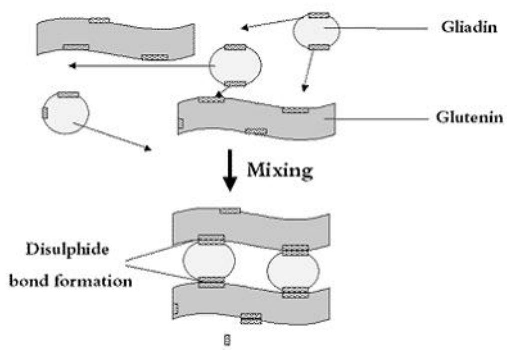


Figure 1. Gluten network formation (Haraldsson, 2010).

Grzybowski and Donnelly (1979) reported that pasta containing low protein cooked faster than pasta with high protein content. The rate of cooking water movement into pasta and subsequent starch gelatinization is slower for high than low protein pasta. Pasta cooking quality could be determined by a physical competition that occurs between protein coagulation into a continuous network and starch swelling during cooking. If protein coagulation prevails, starch is entrapped in the protein network, which supports the minimum loss of starch into the cooking water and increase firmness in cooked pasta. Soft and sticky pasta usually occurs if the latter prevailed where protein coagulated in discreet masses and lacked continuous framework (Grzybowski and Donnelly, 1979).

Typical description regarding the structure of cooked pasta consists of compact matrix with starch granules that are entrapped in a protein network (Petitot et. al., 2009). Starch gelatinization and protein coagulation are the typical changes that were observed in the cooking process. During pasta cooking, high levels of exudates escaped during starch granule gelatinization due to weak or discontinuous protein matrix. Structural transformations of both the starch and proteins are very competitive (i.e. both components are competing for water) and antagonistic (i.e. swelling of starch granules is opposed to formation of protein network) (Petitot et. al., 2009). When starch swells rapidly, protein interaction is slower and thus creates a weaker protein network inside the pasta (Cubadda et. al., 2007).

Texture Analysis of Cooked Pasta

Quality of Pasta

Physical parameters that are commonly associated with dried pasta are color/aesthetic appearance and mechanical strength. Mechanical strength of dried pasta can be defined as the ability of dried pasta to withstand compression forces as an indication of the resistance of the product to shattering during handling and transportation (Marchylo et al., 2004). Improper drying can cause checking and decrease mechanical strength of pasta. The presence of a strong gluten matrix is crucial for high mechanical strength pasta (Cubadda et al., 2007).

Pasta cooking quality can be described in terms of stickiness, firmness, overcooking tolerance, water absorption, degree of swelling and loss of solids to cooking water (Del Nobile et al., 2004). Texture is considered one of the main criteria in assessing overall quality of cooked pasta. Standardization of cooking procedure allows results from different laboratories or facilities and from different people to be compared. Some factors that need to be considered are cooking time, water-to-pasta ratio, hardness and pH of cooking water and time elapsed between draining of cooked pasta and analysis (Marchylo et al., 2004; de la Peña and Manthey 2014; de la Peña et al., 2014).

Sensory Testing

Before the introduction of scientific instruments to measure firmness of cooked pasta, researchers analyzed texture using mastication technique by trained personnel. Sensory evaluation is considered to be the most reliable method for determining textural properties of cooked pasta because panelists are capable of evaluating overall textural characteristics of cooked pasta (Marchylo et al., 2004). A group of panelists was trained to assess firmness, chewiness, gumminess, and adhesiveness of spaghetti strands and these panelists were able to detect the differences among the spaghetti samples for all parameters investigated (Marchylo et al., 2004). They compared the results from the sensory tests with consumer acceptability tests and found that consumers preferred spaghetti that was firm and chewy and was not gummy or adhesive. They concluded that firmness and gumminess parameters were sufficient to predict consumer acceptability. Taste panels were asked to evaluate stickiness parameter of spaghetti and even though it was a success, the authors reported that it is very time consuming and large sample size was needed.

A standard method (TC 34 SC4 7304) for sensory analysis was approved by the International Standards Organization. Panelists were trained to evaluate firmness and surface condition (stickiness) of cooked spaghetti (Marchylo et al., 2004). Other parameters of concern were general appearance, degree of swelling and stickiness. Nine-point rating scales were used as the scoring method for the sensory evaluation. Sensory panel is well-suited when it involves monitoring changes of pasta quality over time. Despite the advantages of using sensory panelists, this method is often criticized as being subjective. Sensory evaluation is subjective and the results vary with panel members due to individual preferences. Sensory analysis can be very time-consuming, expensive and impractical when sample size is limited or large samples are involved (Manthey and Dick, 2012). Due to these constraints, a number of instrumental methods have been developed to overcome these issues.

Instrumental Testing

There are several apparatus, including Texture Profile Analysis (TPA) rig, Ottawa cell, and Pasta blade, that can be used to determine the firmness of cooked pasta quality (Manthey and Dick, 2012). The TPA, which was developed by General Foods Corporation, can measure a number of parameters and is typically used for noodles and pasta texture analysis (Rosenthal, 1999). Spaghetti strands are compressed twice and analysis of the force-time curve obtained gives information about the flexibility and extensibility, cohesiveness, stickiness, adhesiveness, springiness, chewiness and gumminess.

Pasta Blade

The AACCI approved method for testing cooked firmness of pasta uses the Plexiglas Pasta blade (Method 66-50.01, AACCI 1999). Texture evaluation using the Pasta blade is a standard technique practiced in most pasta quality laboratories and is good for traditional straight goods (e.g. spaghetti). Pasta blade is made from Plexiglas material and its cutting surface is 5 cm long and 1 mm wide. In this method, five strands of cooked spaghetti are laid parallel to each other and perpendicular to the Pasta blade. The force and work required to cut through spaghetti are measured using a load cell. Cooked firmness has been well correlated with ‘bite’ characteristic of sensory evaluation (Walsh et al., 1972).

Modified Ottawa Cell

Modified Ottawa Texture Measuring System extrudes sample by pushing it through a grid of heavy wire that is located at the bottom of the test cell. The functionality of Modified Ottawa cell is similar to the Ottawa cell (firmness-stickiness rig). The base of the sample is made out of aluminum and uses plastic plunger (Plexiglas). A plate with holes or wire grid is fitted at the bottom of the 51 mm x 5 mm x 115 mm deep box. This method provides a shallow sample base which is perfectly suited for pasta analysis (Manthey and Dick, 2012).

Glutograph

Glutograph is a simple rheometer that is built by Brabender (Glutograph-E, Brabender GmBH and Co. Duisburg, Germany) to determine the stretch and relaxation values of washed wet gluten for wheat (Rosenthal, 1999). Alamri et al. (2009) concluded that the glutograph had potential as a rheological instrument in assessing quality properties of semolina samples for dough strength among different cultivars.

The glutograph consists of two corrugated plates that are parallel and mounted a fixed distance from each other. The grooves on the plates prevent the sample from sliding during shearing. One of the plates deflects against the other one that is stretching the sample. Washed gluten obtained from the glutomatic (Perten Instruments, Springfield, IL) is placed in between these two plates and excess gluten is removed. The lower plate turns at a constant force to a preset deflection point while the upper plate stays still. Depending on the quality of the sample, it is sheared shorter or longer period of time up to a deflection of 800 units (=42 º). If the sample reaches 800 line, the shearing disk is unloaded automatically. Useful information that is obtained from glutograph is shear time or stretching (STR, sec), which is the time to reach the deflection or shear angle (extensibility) and relaxation (RX, BU) which is the recovery of the sample after 10 sec (elasticity) (Alamri et al., 2009).

The large deformation creep-recovery measurements have been studied by researchers using more sophisticated rheometers. A recent study was conducted to evaluate gluten strength of durum wheat dough and the researchers found that maximum creep strain was important in assessing durum wheat dough strength (Sissons, 2008). Wang and Sun (2002) used creep-recovery measurement of flour-water dough with a dynamic mechanical analyzer to study gluten strength.

Creep-recovery technique has long been applied in determining rheological properties of dough. Glutograph produces output that resembles the output of those obtained using creep and recovery method. An example of the output from glutograph is shown on Figure 2. The diagram shows both rising curve (stretching process) and falling curve (recovery of the sample). Shearing time (in seconds) indicates the time needed to reach certain preset deflection point depending upon the stretching capability of the sample. Recovery of the sample indicates the elasticity of the sample. A typical creep-recovery curve has six deformation regions; instantaneous elastic deformation, retarded elastic deformation, equilibrium deformation, instantaneous recovery, delayed elastic recovery and steady recovery as shown on Figure 3. Instantaneous elastic deformation is where a sudden constant force is being placed, which causes rapid deformation. Retarded elastic deformation is the stage right after instantaneous where deformation continues but at much slower rate. At one point, the strain reaches the equilibrium point between elastic and viscous components in linear manner. Next stage is instantaneous recovery where force decreases significantly and ultimately results in a steep slope. Delayed elastic recovery occurs when the sample continues to recover but at a slower rate. Finally, the dough recovery reaches its equilibrium point and stops. The strain was seen increased with time and came to a steady state where strain rate remained at constant. In the recovery stage, dough strain was partially recovered as time increased after the force was removed (Wangand Sun, 2002).

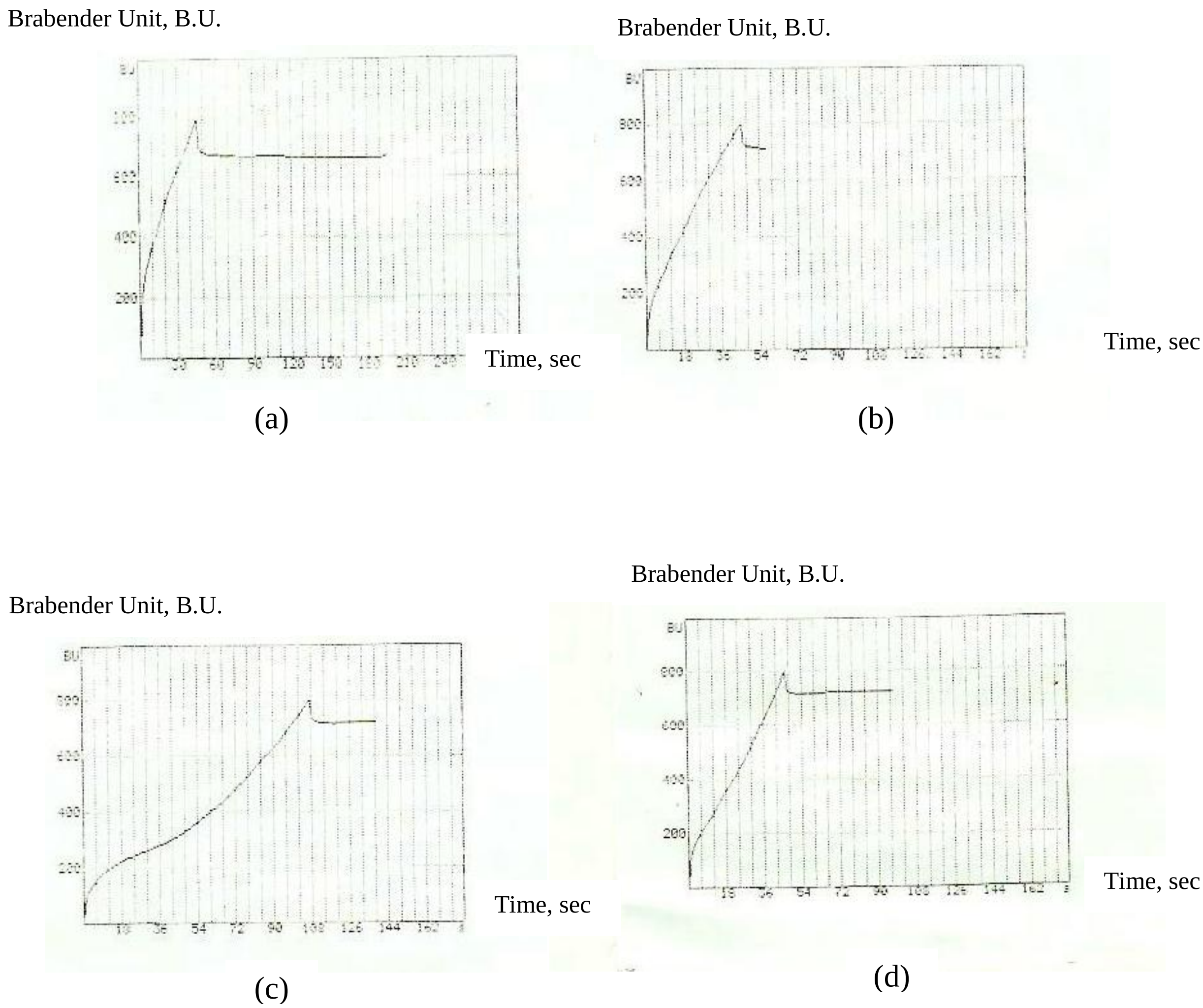


Figure 2. Output from glutograph for drill strip sample with (a) 1,000, (b) 2,000, (c) 3,000 and (d) 4,000 impulses

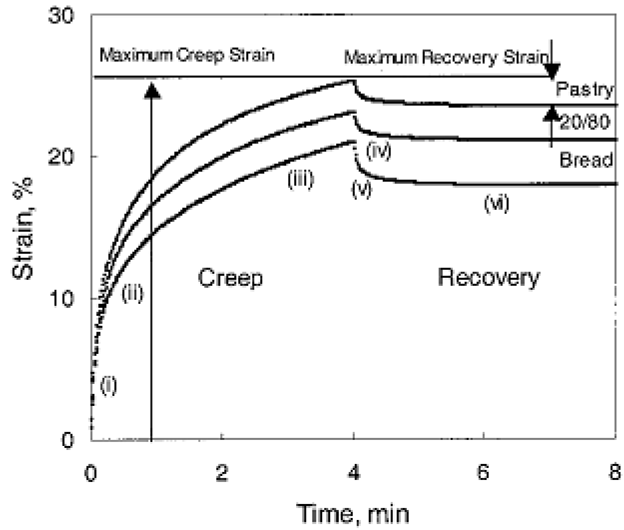


Figure 3. Six deformation regions of creep-recovery curve: (i) instantaneous elastic deformation, (ii) retarded elastic deformation, (iii) equilibrium deformation, (iv) instantaneous recovery, (v) delayed elastic recovery, and (vi) steady recovery (Wang and Sun, 2002)

MATERIALS AND METHODS

Spaghetti Samples

Commercial spaghetti samples were obtained from a local grocery store. Remaining spaghetti samples were made in the Durum Wheat Quality and Pasta Processing Laboratory in the Department of Plant Sciences, North Dakota State University as described below.

The semolina and semolina-nontraditional ingredient blends were mixed using a cross flow blender, hydrated to 32% moisture content and extruded as spaghetti using a semi-commercial laboratory extruder (DEMACO, Melbourne, FL). Extrusion occurred under the following conditions: extrusion temperature, 45ºC; mixing chamber vacuum, 46 cm of Hg; an auger extrusion speed, 25 rpm. The extrusion auger had a length to diameter ratios of 8.1:1, a constant root diameter and uniform pitch the entire length of the auger. Spaghetti was extruded using a die with 84 circular Teflon® coated openings 1.5 mm in diameter. Spaghetti from drill strips were dried using a low temperature (40°C) drying cycle while spaghetti containing non-traditional ingredients were dried using a high temperature (70°C) drying cycle. Dried spaghetti samples were then stored in the dark under ambient conditions until further analysis.

Cooking Procedure

Spaghetti (10 g) was broken into lengths of approximately 5 cm and cooked in 350 mL of rapidly boiling distilled water. At the cooked time, the cooked samples were poured into a Büchner funnel, rinsed with distilled water (25 mL), and placed in distilled water until used for cooked texture determination.

Cooked time was determined using AACCI Approved Method 66-50 (1999). Cooked time is defined as the time required for the white starchy core in the center of the pasta to disappear. To determine cooked time, three to five strands of spaghetti were removed during cooking and crushed between two Plexiglas plates. This process was repeated every 30 sec beginning after 7 min of cooking.

Cooked Texture

Pasta Blade

Firmness of cooked spaghetti was analyzed using a Texture analyzer (TA-XT2) (Texture Technologies Corp., Scarsdale, NY) as shown on Figure 4. Force (g) and work (g.cm) needed to shear the spaghetti were measured and recorded. High force and work values indicate a firm product. Settings for the texture analyzer were: test speed 0.2 mm sec^{-1}; load cell mass 5 kg and blade distance stopping short of base plate of 1.0 mm. The test was done three times per cooked sample.

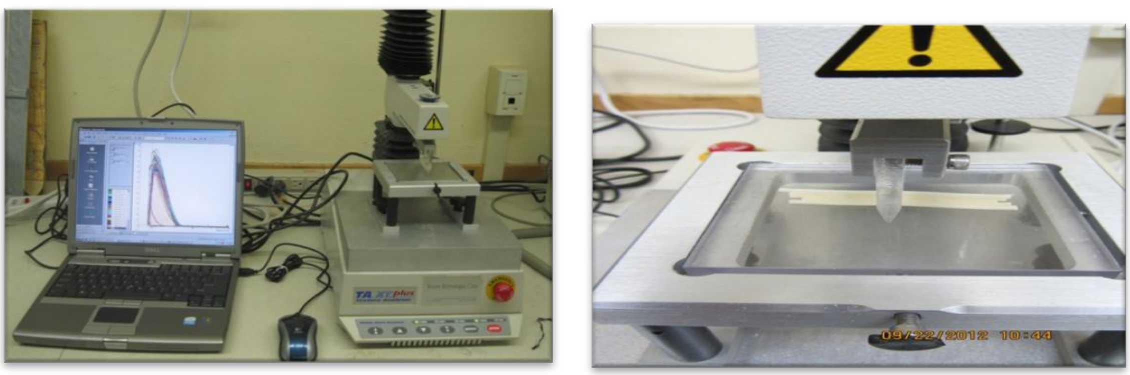
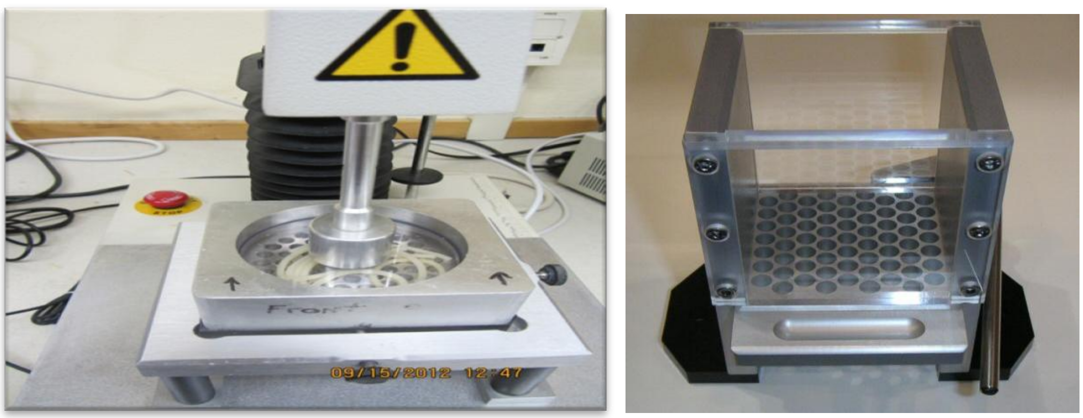


Figure 4. Texture analyzer (TA-XT2) used to measure spaghetti firmness

Modified Ottawa Cell

The principle behind Ottawa cell (Figure 5) is that shear stress applied to a specimen is produced as a result of forward extrusion using a TA-XT2 texture analyzer. Spaghetti samples were compressed as the plunger of the Ottawa cell descends. If deformation proceeds, the sample was extruded though holes, which are located at the bottom of the cell. Firmness is associated with the force required to extrude the samples through the insert.



(a) (b)

Figure 5. (a) Modified Ottawa cell (b) Cell chamber

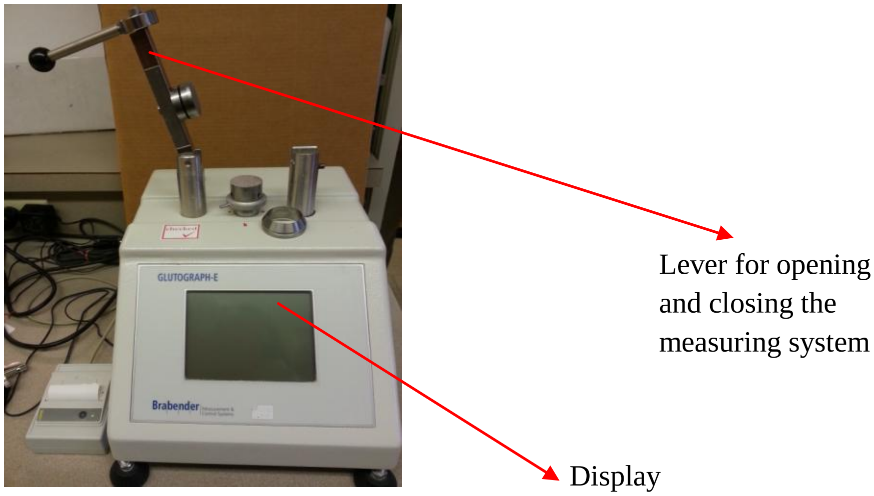
Approximately 4 g of cooked spaghetti was transferred to the Ottawa cell. The settings for the Ottawa cell were: pre-test speed 5.0 mm/sec, test speed 5.0 mm/sec, and trigger force 10.0 g. The "run" tab on the Modified Ottawa cell program was pressed to analyze the sample. The analysis would be done in approximately 30 sec. The test was run three times per cooked sample.

Glutograph

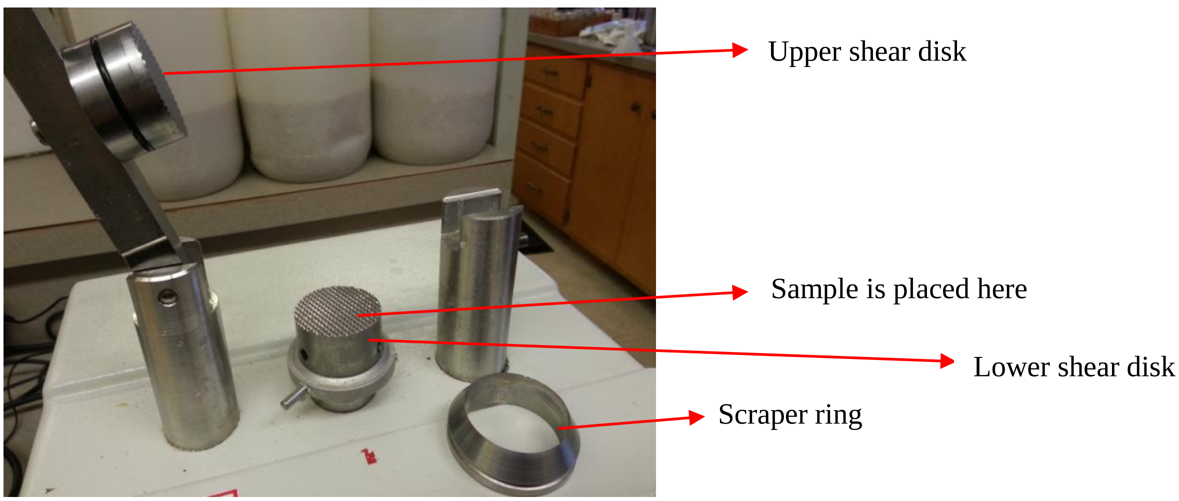
Cooked spaghetti samples were placed between two parallel, round, corrugated plates that are mounted at a defined distance opposite each other (Figure 6). The plates were clamped together and material extending beyond the edges was cut and removed. Thus, there was a fixed volume of material based on diameter and height between the plates. Cooked spaghetti samples were placed side-by-side beginning in the middle of the plate. One to six strands were evaluated.

Glutograph settings that can be varied include: impulses (1,000 to 10,000) and fixed weight added to pulley. Impulse setting is a variable that can be set by the program. These settings vary from 1,000 to 10,000 in units of 1,000. Adding weight to the pulley shortens the shearing time and is used with strong gluten samples such as found with bread wheat (Anonymous 2004).

Data obtained from glutograph are shear time or stretching (STR) that was measured in sec and relaxation that was measured in Brabender Units. Shear time is the time to reach the deflection or shear angle (extensibility). Relaxation is the recovery of the sample after 10 sec (elasticity), where complete relaxation would be recorded by the curve returning to the X-axis. Output of the glutograph is represented in Figure 7. The analysis usually took about 1-2 minutes depending on the sample and the settings set on the glutograph. The result of the analysis was transferred automatically into the computer.



(a)



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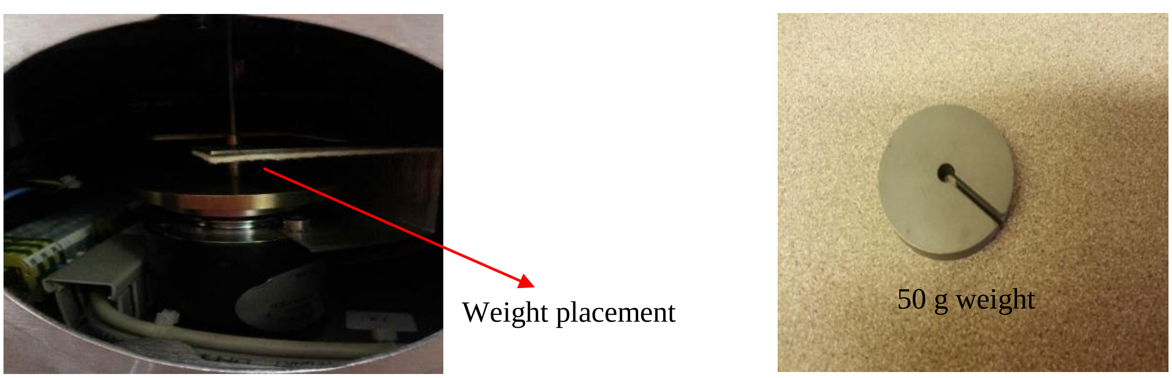


(c)

Figure 6. (a) Glutograph (b) Top view (c) Loading weight where the lower the loading weight, the longer the shearing time

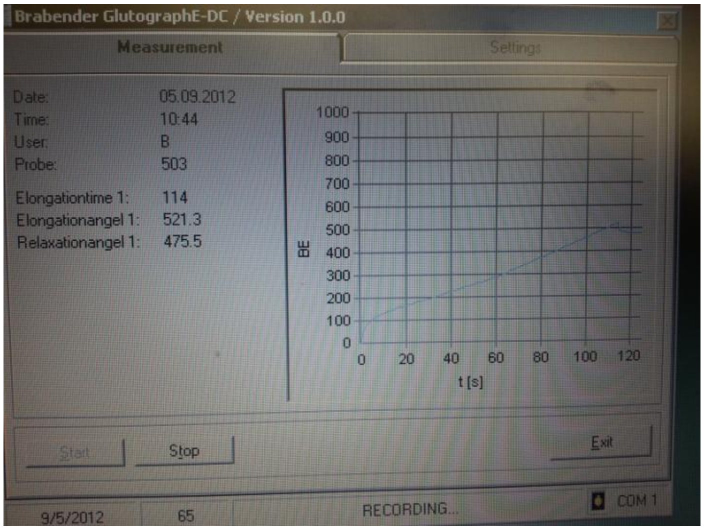


Figure 7. Data output of glutograph of spaghetti made with durum wheat semolina

Experimental Plan

Glutograph: Method Development

Impulses, Cooking Time, Strand Number and Weight

For this experiment, spaghetti was cooked to 11, 13 and 15 min. One to six strands of cooked spaghetti were placed between the corrugated plates. Impulses evaluated ranged from 1,000 to 10,000. Tests were run with and without weight.

First, the data were analyzed where with and without weight were separate experiments. In this case, the experimental design was a randomized complete block with a split-split-plot arrangement, where whole-plots were cooking time (11, 13, 15 min), sub-plots were impulse (1,000 to 10,000), and sub-sub-plots were number of strands (1 to 6). Each treatment was replicated three times and data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test would be significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Impulses, Cultivar and Strand Number

For this experiment, spaghetti made from 2010 durum drill strip samples was used. Spaghetti was cooked 12 min. Samples were tested with three and four strands and 1,000 to 5,000 impulses. Glutograph was configured with the weight.

The experimental design was a randomized complete block with a split-split plot arrangement, where whole-plots were impulses, sub-plots were cultivar, and sub-sub-plots were number of strands. Each treatment was replicated three times and data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Impulses and Nontraditional Ingredients

Spaghetti was made from semolina blends with whole wheat flour and coarse and fine particle size flaxseed flour and soy flour. Spaghetti was cooked 12 min. Samples were tested with three strands and 1,000 to 5,000 impulses. Glutograph was configured with weight.

The experimental design for both experiments was a randomized complete block with a split-plot arrangement, where whole-plots were impulses and sub-plots were spaghetti formulations. Each treatment was replicated three times and data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Glutograph: Validation Development

Impulses and Cultivar

For this experiment, spaghetti made from 2011 drill strip samples was used. Spaghetti was cooked 12 min. Samples were tested with three strands and 3,000 and 4,000 impulses. Glutograph was configured with the weight.

The experimental design was a randomized complete block with a split-plot arrangement, where whole-plots were impulses and sub-plots were cultivars. Each treatment was replicated seven times and data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Spaghetti Containing Nontraditional Ingredients

Spaghetti was made from semolina blends with oat flour, soy flour, and whole wheat flour (Figure 8). Spaghetti was cooked 12 min. Samples were tested with three strands and 3,000 and 4,000 impulses. Glutograph was configured with weight.

The experimental design for both experiments was a randomized complete block with a split-plot arrangement, where whole-plots were impulses and sub-plots were spaghetti formulations. Each treatment was replicated three times and data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Figure 8. Nontraditional spaghetti (left to right: durum, whole wheat, semolina and whole wheat, flaxseed 10% and 20%, oat flour 10% and 20%, soy flour 10% and 20%)

Pasta Blade and Modified Ottawa Cell

Experimental design used was a randomized complete block. Each treatment was replicated three times. Data was subjected to an analysis of variance (ANOVA) using the Statistical Analysis System, SAS (9.2) (SAS Institute, Cary, NC). F-Test was significant at $P \leq 0.05$. Treatment means were separated by Fisher's protected least significant difference test calculated at $P = 0.05$.

Pearson correlations were run on firmness values obtained by Pasta blade and TPA factors obtained by Ottawa cell and the Glutograph parameters: stretch time, strain, drop and percent recovery.

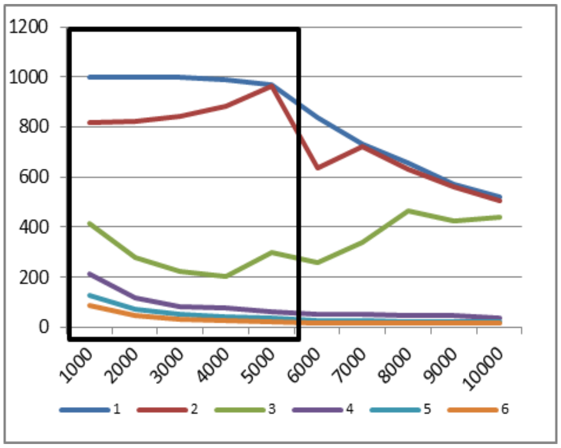
RESULTS AND DISCUSSION

Procedure Development

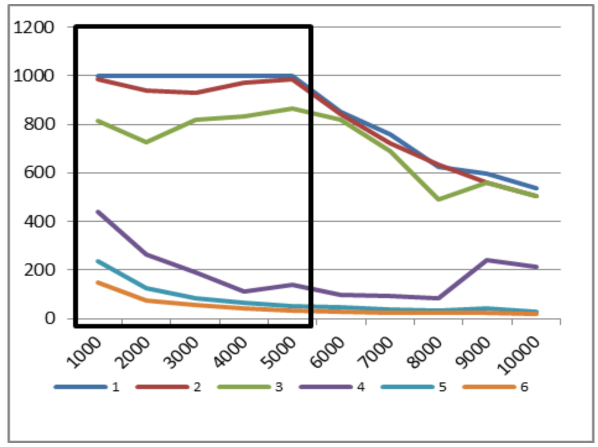
Glutograph variables (strain, stretch, and percent recovery) were plotted against impulses and number of strands of spaghetti (Figures 9-11) and compared with glutograph configured with and without weight. The goal was to select settings that resulted in the mid-region of the figure, avoiding those that resulted in data that plotted either extreme top or bottom. The reasoning was that mid-range values should be able to show an increase or decrease in response, whereas high values could only show a decline in response and low values could only show an increase in response.

Figure 9 shows the plot of strain against impulse with and without added weight for spaghetti samples that were cooked 11, 13 and 15 min, respectively. Cooking time main effect was not significant for strain (Table 1). Interactions with cooking time were significant for strain. The overall ranking of strain value at a given impulse was similar regardless of cooking time (Figure 9). For example, all the spaghetti samples had 1,000 B.U. (strain value) at 1,000 impulse regardless of cooking time. Impulse by strand interaction was significant for strain (Table 1). Strain values were greatest with one and two strands, intermediate with three strands, and lowest with four, five and six strands. A high strain value (one and two strands) indicates that the spaghetti strands did not cause much resistance to rotation of plates. Conversely, a low strain value (four, five, and six strands) did cause substantial resistance to the rotation of plates.

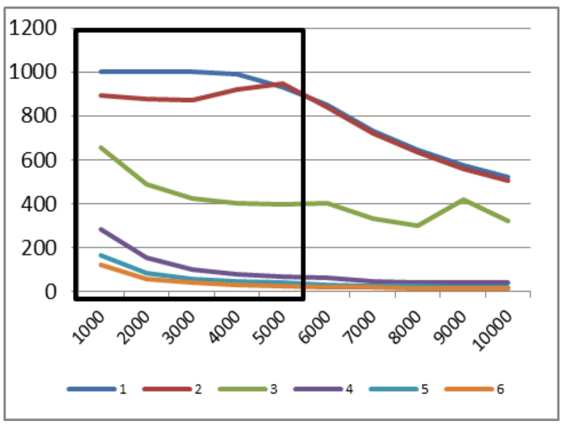
Impulses from 1,000 to 5,000 had little effect on strain values (Figure 9). However, impulses above 5,000 caused a decline in strain value for one and two strands and tended to cause an increase in strain value with three strands particularly with spaghetti cooked 11 and



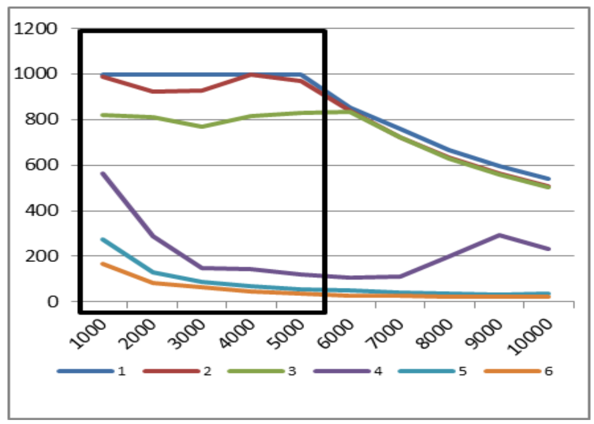
11 minutes



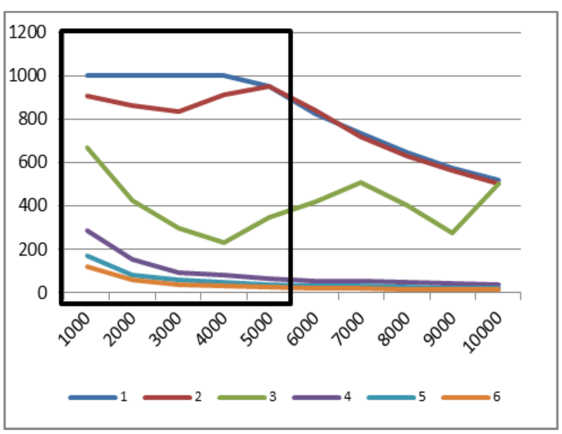
11 minutes



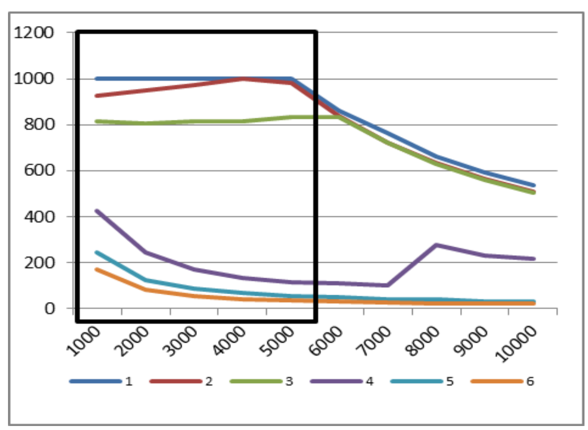
13 minutes



13 minutes



15 minutes

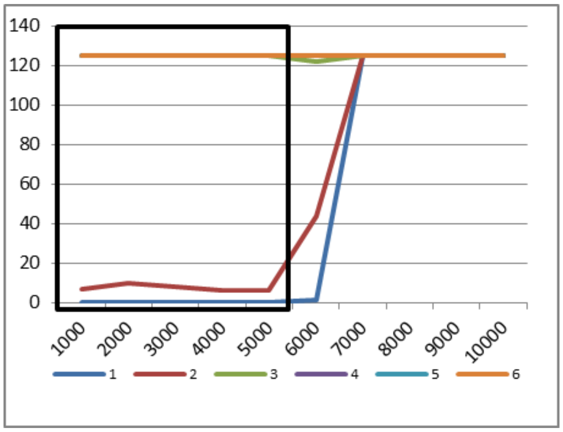


15 minutes

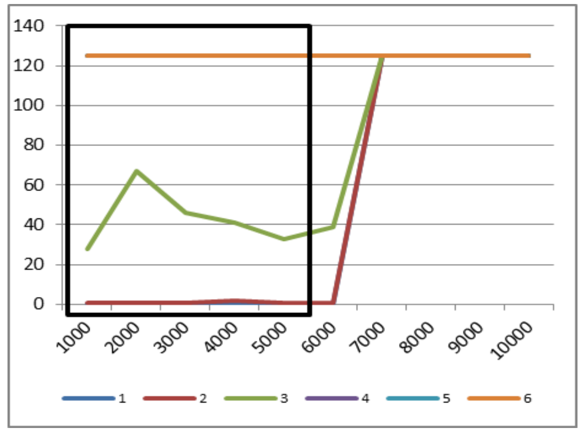
(a) With weight

(b) Without weight

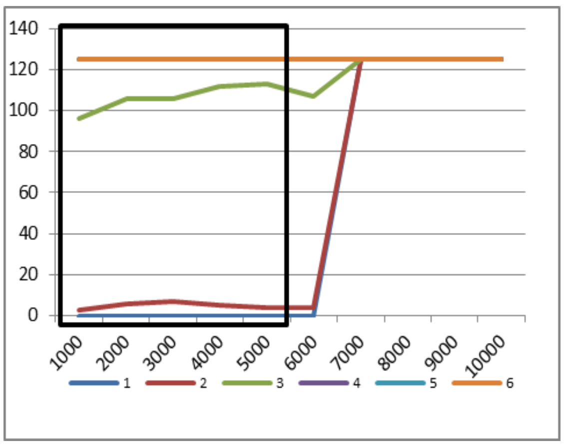
Figure 9. Strain against impulse (a) with and (b) without weight for spaghetti cooked 11, 13, 15 minutes respectively



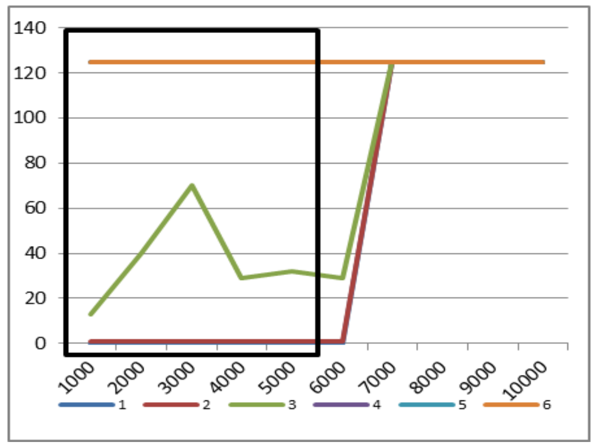
11 minutes



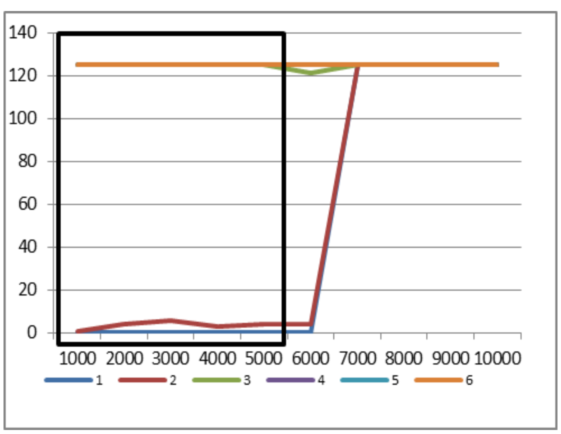
11 minutes



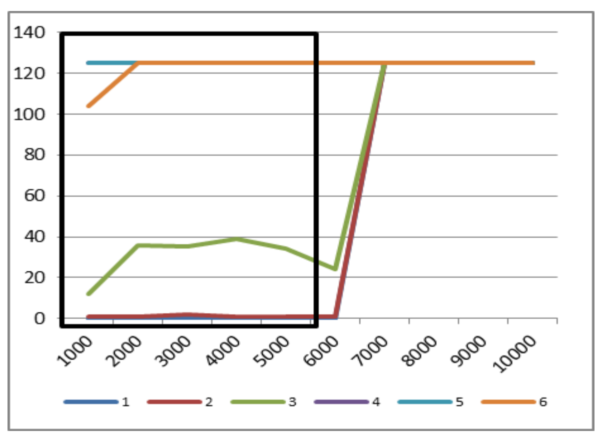
13 minutes



13 minutes



15 minutes

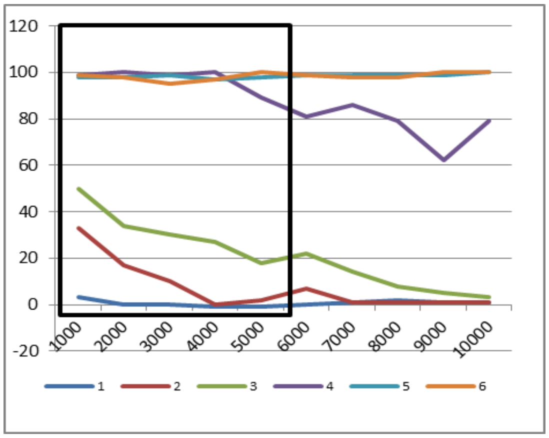


15 minutes

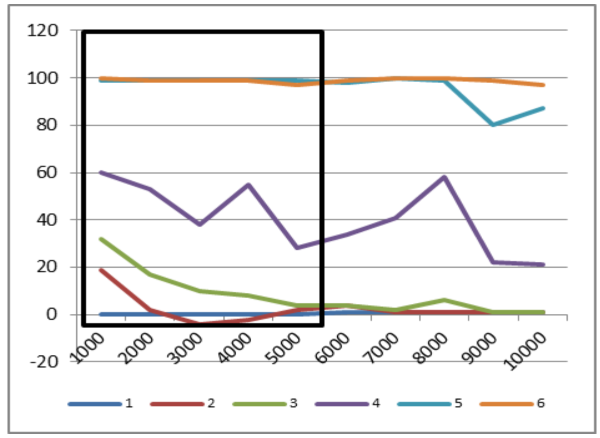
(a) With weight

(b) Without weight

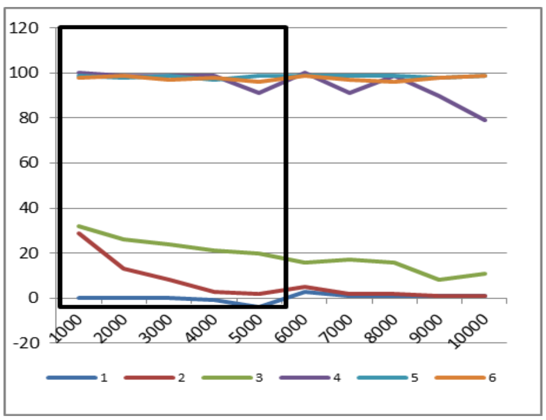
Figure 10. Stretch time against impulse (a) with and (b) without weight for spaghetti cooked 11, 13, 15 minutes respectively



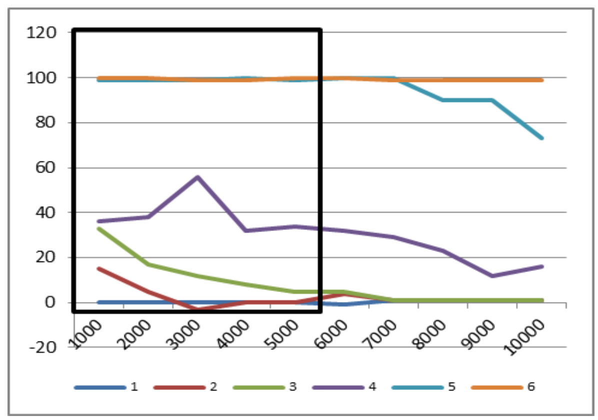
11 minutes



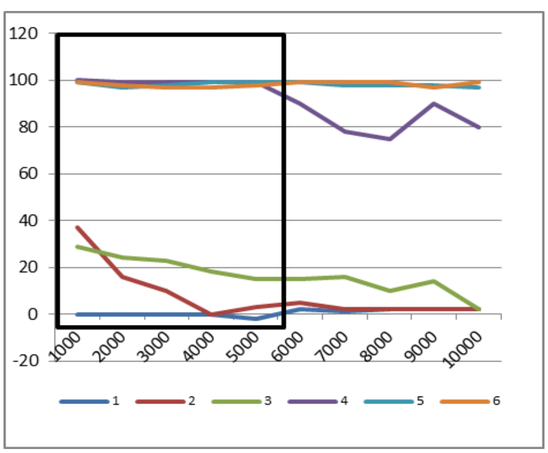
11 minutes



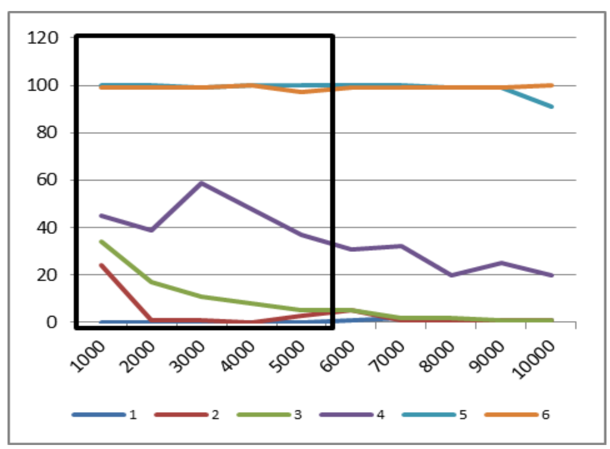
13 minutes



13 minutes



15 minutes



15 minutes

(a) With weight

(b) Without weight

Figure 11. Percent recovery against impulse (a) with and (b) without weight for spaghetti cooked 11, 13, 15 minutes respectively

Table 1. Analysis of variance for glutograph configured with no weight for strain, stretch time, and percent recovery of spaghetti cooked 11, 13, and 15 min, and tested with 1-6 strands and 1,000 to 10,000 impulses.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	2	8,257	0.89	0.4106
	Cooking time (CT)	2	31,200	0.53	0.625
	Error a (CT*rep)	4	58,879	6.37	<0.0001
	Impulse	9	311,226	31.01	<0.0001
	CT*Impulse	18	8647	0.86	0.6236
	Error b (CT*Impulse*rep)	54	10,037	1.09	0.329
	Strand	5	11,814,835	1,277.47	<0.0001
	CT*Strand	10	8,612	0.93	0.5046
	Impulse*Strand	45	71,151	7.69	<0.0001
	CT*Impulse*Strand	90	4,506	0.49	1
	Error c	300	9,249		
Stretch Time	Rep	2	95	1.51	0.223
	Cooking time (CT)	2	324	0.92	0.4695
	Error a (CT*rep)	4	352	5.58	0.0002
	Impulse	9	24,885	489.18	<0.0001
	CT*Impulse	18	49	0.96	0.5166
	Error b (CT*Impulse*rep)	54	51	0.81	0.8298
	Strand	5	124,329	1970.84	<0.0001
	CT*Strand	10	223	3.53	0.0002
	Impulse*Strand	45	9,236	146.41	<0.0001
	CT*Impulse*Strand	90	42	0.67	0.9875
	Error c	300	63		
Percent recovery	Rep	2	277	5.57	0.0042
	Cooking time (CT)	2	27	0.14	0.8715
	Error a (CT*rep)	4	191	3.83	0.0047
	Impulse	9	959	16.72	<0.0001
	CT*Impulse	18	50	0.87	0.6159
	Error b (CT*Impulse*rep)	54	57	1.15	0.2308
	Strand	5	208,036	4,180.98	<0.0001
	CT*Strand	10	108	2.17	0.0198
	Impulse*Strand	45	284	5.7	<0.0001
	CT*Impulse*Strand	90	39	0.77	0.9249
	Error c	300	53		

15 min. There was little to no rotation of the plates for four, five, and six strands with impulses above 5,000.

Decrease in strain with one or two strands indicate that as impulse increased above 5,000, the overall resistance to twist increased, since one or two strands were enough to prevent full rotation within the 125 sec time limit. Strain is the measure of how much or to what extent a sample can be stretched. Thus, one and two strands did not provide adequate resistance to stretching while 4, 5 and 6 strands resulted in too great of resistance. Differences in strain among strands were greater with impulses from 1,000 to 5,000 than from 6,000 to 10,000.

Cooking time main effect and interactions with cooking time were not significant for strain measured by glutograph configured with weight (Table 2). Thus, cooking time did not seem to affect strain when the weight was added to the glutograph. Impulse by strand interaction was significant for strain measured by glutograph configured with weight. Adding weight to the glutograph generally reduced the resistance to turning of the plates, as seen by the increased strain values with three, four, five, and six strands, particularly with 1,000 to 5,000 impulses as shown on Figure 9. Differences in strain were greater with impulses from 1,000 to 4,000 than from 5,000 to 10,000. The strain value with three strands became similar to those for one and two strands.

Stretch time is the time required for the plates to rotate and strain to reach 800 units. The maximum stretch time was set for 125 sec. Impulse by strand interaction was significant for stretch time with glutograph configured without a weight (Table 1). Stretch time was either very low or was high. For example, stretch time was 125 sec for three, four, five, and six strands at 1,000 to 6,000 impulses and was 0 to 10 sec for one and two strands (Figure 10). All strand numbers had a stretch time of 125 sec with 7,000 to 10,000 impulses. Although cooking time by strand interaction was significant, there were no practical differences in stretch time among the three cooking times.

Impulse by strand interaction was significant for stretch time with glutograph configured with added weight. The added weight did not appear to affect stretch times for one, two, four, five or six strands (Figure 10). Stretch times for one and two strands were short and for four, five, and six strands were long. However, stretch times for three strands were intermediate to those of the other strands (Figure 10). Effect of cooking time on stretch time was not statistically significant but with three strands tended to be variable but might be differentiated when tested using 2,000 impulses. Stretch time of three strands using 2,000 impulses was longest (65 sec) with 11 min cook time, intermediate (40 sec) with 13 min cook time, and shortest (36 sec) with 15 min cook time. A short stretch time would indicate less resistance to rotation from spaghetti cooked 15 min compared to a long stretch time from spaghetti cooked 11 min.

Percent recovery is a measure of the elasticity of the cooked spaghetti. Complete recovery (100%) occurs when the plate is able to rotate back to initial position. Impulse by strand interaction was significant for percent recovery with glutograph configured without weight (Table 1). Four, five, and six strands allowed little or no rotation of the plates and showed or nearly showed 100% recovery (Figure 11). Conversely, one and two strands had complete rotation. Percent recovery for one strand was zero, regardless of cooking time, impulse, or weight added. One strand does not provide resistance to rotation or elasticity to return to original state. Two and three strands show some tendency to resist rotation and had intermediate percent recovery, when without weight.

Figure 11 shows that percent recovery without weight for four, five and six strands was at 100% when measured at 1,000 to 4,000 impulses. Above 4,000 impulse, recovery with four strands declined up to 40 percentage units for undercooked (11 min) spaghetti and 20 percentage units for cooked (13 min) and overcooked (15 min) spaghetti. Intermediate results occurred for three strands with 1,000 to 6,000 impulses and with two strands with 1,000 to 3,000 impulses. No recovery was detected for one strand regardless of impulse level.

Impulse by strand interaction was significant for percent recovery with glutograph configured with weight (Table 2). Percent recovery tended to decline with increased impulse number (Figure 11). With the weight, recovery was greatest with 5 and 6 strands, intermediate with four strands and least with one, two, and three strands. Percent recovery increased with increasing number of strands, with no recovery with one strand and total recovery with five and six strands. Total recovery with five and six strands is a mathematical anomaly since neither allowed stretching to occur. For the glutograph configured with weight, intermediate recovery occurred with four strands regardless of impulses and with three strands with 1,000 to 4,000 impulses.

The data from this experiment indicate that differences in parameters measured tended to be greater with lower than with higher impulses. Within the 1,000 to 5,000 impulse range, three and four strands tended to provide mid-range values capable of increasing or decreasing in response to a given treatment. Addition of weight to the glutograph produced better representation of the outcome than without weight.

Table 2. Analysis of variance for glutograph configured with added weight for strain, stretch time, and percent recovery of spaghetti cooked 11, 13, and 15 min, and tested with 1-6 strands and 1,000 to 10,000 impulses.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	2	22,955	5.67	0.0038
	Cooking time (CT)	2	5,961	1.2	0.3917
	Error a (CT*rep)	4	4,986	1.23	0.2972
	Impulse	9	537,158	102.75	<0.0001
	CT*Impulse	18	3,055	0.58	0.8954
	Error b (CT*Impulse*rep)	54	5,228	1.29	0.0954
	Strand	5	12,876,293	3,182.49	<0.0001
	CT*Strand	10	1,359	0.34	0.9709
	Impulse*Strand	45	83,179	20.56	<0.0001
	CT*Impulse*Strand	90	1,247	0.31	1
	Error c	300	4,046		
Stretch Time	Rep	2	110	1.98	0.1395
	Cooking time (CT)	2	116	2.21	0.2256
	Error a (CT*rep)	4	53	0.95	0.4382
	Impulse	9	46,178	878.42	<0.0001
	CT*Impulse	18	45	0.86	0.6277
	Error b (CT*Impulse*rep)	54	53	0.95	0.5833
	Strand	5	127,931	2,304.31	<0.0001
	CT*Strand	10	68	1.22	0.2765
	Impulse*Strand	45	9,592	172.77	<0.0001
	CT*Impulse*Strand	90	43	0.77	0.9313
	Error c	300	56		
Percent recovery	Rep	2	359	4.79	0.009
	Cooking time (CT)	2	194	5.1	0.0794
	Error a (CT*rep)	4	38	0.51	0.7305
	Impulse	9	1,048	10.49	<0.0001
	CT*Impulse	18	76	0.75	0.7398
	Error b (CT*Impulse*rep)	54	100	1.33	0.0703
	Strand	5	191,132	2,552.25	<0.0001
	CT*Strand	10	147	1.96	0.0372
	Impulse*Strand	45	299	3.99	<0.0001
	CT*Impulse*Strand	90	54	0.72	0.9668
	Error c	300	75		

Spaghetti Made from Different Cultivars

Impulse by strand interaction and cultivar by strand interaction were significant for strain (Table 3). Strain was lower with four than with three spaghetti strands, regardless of cultivar (Table 4). Four spaghetti strands had greater resistance to turning of the plate. Cultivar ranking depended on the strand number. For both three and four spaghetti strands, Mountrail was greatest followed by Rugby. The biggest difference in ranking came with Lebsock, which was ranked sixth with three spaghetti strands and third with four strands.

At each impulse, strain was lower with four than with three spaghetti strands (Table 5), Strain with three spaghetti strands did not differ with impulses from 1,000 to 5,000. With four spaghetti strands, strain was greatest with 1,000 impulses, intermediate with 2,000, 3,000, and 4,000 impulses and least with 5,000 impulse. Thus, resistance to twisting the plate generally increased (lower strain value) as impulse increased.

Impulse, cultivar, and strand number main effects were significant for stretch time. (Table 3). Stretch time was greater with Lebsock, Ben, Dilse, and Maier than with Mountrail and Rugby. Short stretch time indicates that the cooked spaghetti offered low resistance to rotation of the plates. Mountrail and Rugby form a weak gluten matrix as indicated by their gluten index of 38 and 2, respectively. In comparison, gluten index for Lebsock, Ben, Dilse, and Maier were 80, 76, 70, and 61. Stretch time was lowest with 1,000 impulses (Table 5). Stretch time was similar for impulses from 2,000 to 5,000. The short stretch time indicates that resistance to twisting the plates was lowest with 1,000 impulse setting.

Cultivar by strand interaction and impulse and cultivar main effects was significant for percent recovery (Table 3). Except for Mountrail, percent recovery was greater with four spaghetti strands than with three strands (Table 4). With Mountrail, percent recovery was similar with three or four strands. Although not statistically different, percent recovery tended to be greatest with Lebsock (16.2%) and least with Rugby (13.3%) when tested with three strands. Cultivars differed in their percent recovery when tested with four strands. Cultivar ranking from highest to lowest was: Maier (62.7%) > Dilse (50.9%) and Lebsock (49.2%) > Ben (34.8%) and Rugby (27.8%) > Mountrail (20.4%). Percent recovery was greatest with 1,000 impulse (43.2%) (Table 5). Although not statistically different, percent recovery tended to decline as impulse increased from 2,000 (26.7%) to 5,000 (20.9%).

These results indicate that for stretch time, three spaghetti strands would be better than four strands since results with four strands were only five sec from maximum time while results with three strands were 22 sec from the shortest time. For strain, four spaghetti strands seem to be better since results with three strands reached the top setting of 800 units while four strands ranged from 233 to 491 units. Four spaghetti strands more clearly differentiated cultivars compared to results with three strands. Impulse particularly between 2,000 and 5,000 did not differ greatly in their effect on stretch time, strain, or percent recovery.

Table 3. Analysis of variance for glutograph configured with weight for strain, stretch time, and percent recovery of spaghetti made with six durum cultivars grown in 2010 drill strip test and tested with 3 and 4 strands and 1,000 to 5,000 impulses.

Variable	**Source**	**df**	**MS**	**F value**	**Pr>F**
Strain	Rep	2	331,569	24.24	<0.0001
	Impulse	4	218,335	27.38	0.0001
	Error a (Impulse*rep)	8	7,973	0.58	0.7879
	Cultivar	5	91,562	4.54	0.0017
	Impulse*Cultivar	20	11,217	0.56	0.9239
	Error b (Impulse*Cultivar*rep)	50	20,167	1.47	0.075
	Strand	1	11,182,950	817.64	<0.0001
	Impulse*Strand	4	246,981	18.06	<0.0001
	Cultivar*Strand	5	51,062	3.73	0.0052
	Impulse*Cultivar*Strand	20	6,077	0.44	0.9766
	Error c	60	13,677		
Stretch Time	Rep	2	4,779	18.91	<0.0001
	Impulse	4	1,234	5.92	0.0162
	Error a (Impulse*rep)	8	208	0.82	0.5843
	Cultivar	5	919	4.04	0.0037
	Impulse*Cultivar	20	191	0.84	0.6557
	Error b (Impulse*Cultivar*rep)	50	228	0.9	0.6455
	Strand	1	433,848	1,717.15	<0.0001
	Impulse*Strand	4	179	0.71	0.5888
	Cultivar*Strand	5	229	0.91	0.4826
	Impulse*Cultivar*Strand	20	177	0.7	0.8108
	Error c	60	253		
Percent recovery	Rep	2	3,231	9.83	0.0002
	Impulse	4	2,898	17.56	0.0005
	Error a (Impulse*rep)	8	165	0.05	0.8499
	Cultivar	5	2,086	6.95	<0.0001
	Impulse*Cultivar	20	170	0.57	0.9168
	Error b (Impulse*Cultivar*rep)	50	300	0.91	0.6267
	Strand	1	31,277	95.17	<0.0001
	Impulse*Strand	4	456	1.39	0.2493
	Cultivar*Strand	5	1,753	5.33	0.0004
	Impulse*Cultivar*Strand	20	144	0.44	0.9785
	Error c	60	328		

Table 4. Mean[a] stretch time (averaged over impules and strands) and mean values for strain and percent recovery (averaged over impulse) for spaghetti made from different cultivars tested with glutograph configured with weight.

		Strands		Strands	
		3	4	3	4
Durum cultivar	Stretch time, sec	Strain, BU		Percent Recovery	
Rugby	68.0 b,c	855 a A	385 b B	13.3 a B	27.8 d A
Mountrail	61.4 c	861 a A	491 a B	14.2 a B	20.4 e B
Ben	71.5 a,b	842 a,b,c A	296 d B	13.8 a B	34.8 d A
Maier	72.1 a,b	825 b,c A	233 e B	14.9 a B	62.7 a A
Dilse	73.6 a,b	819 c,d A	261 e B	15.3 a B	50.9 a,b A
Lebsock	77.6 a	793 d A	337 c B	16.2 a B	49.2 b,c A

[a]Means within each column followed by the same small letter and means within each row followed by the same large letter are not significantly different at P=0.05.

Table 5. Mean[a] stretch time and percent recovery (averaged over cultivar and strand) and mean values for strain (averaged over cultivar) for spaghetti made from different cultivars tested with glutograph configured with weight.

			Strands	
			3	4
Impulse	Stretch time, sec	Percent recovery	Strain, BU	
1000	60.8 b	43.2 a	824 a A	600 a B
2000	74.4 a	26.7 b	819 a A	351 b B
3000	73.3 a	25.8 b	841 a A	262 c,d B
4000	69.9 a,b	22.3 b	853 a A	274 b,c B
5000	75.0 a	20.9 b	825 a A	183 d B

[a]Means within each column followed by the same small letter and means within each row followed by the same large letter are not significantly different at P=0.05.

Spaghetti Made with Nontraditional Ingredients

Ingredient and impulse main effects were significant for strain, stretch time, and percent recovery (Table 6). Strain was greatest for spaghetti containing coarse flaxseed flour, intermediate for spaghetti containing semolina and semolina with fine flaxseed flour, and least for spaghetti containing wholewheat flour and wholewheat flour containing fine flaxseed flour (Table 7). Conversely, stretch time was greatest for cooked spaghetti containing wholewheat flour and wholewheat flour and fine flaxseed flour, intermediate for cooked spaghetti containing semolina and semolina with fine flaxseed flour, and least for cooked spaghetti containing coarse flaxseed flour. Thus, strain and stretch time differentiated the nontraditional pastas into same groups. Percent recovery grouped the spaghetti samples differently than did strain and stretch time. Recovery was greatest with spaghetti made with 100% wholewheat flour, intermediate with spaghetti made with 100% semolina or semolina:wholewheat 49:51; and least with spaghetti that contained flaxseed flour.

Impulse main effect was significant for strain, stretch time, and percent recovery (Table 6). Strain values decreased as impulse increased from 1,000 to 4,000 (Table 8). Interestingly, the greatest strain value occurred with the 5,000 impulse setting. Stretch time was greater with 2,000, 3,000, and 4,000 impulses than with 1,000 or 5,000 impulses. The greatest percent recovery occurred with 1,000 impulses. Recovery continued to decrease as impulse increased from 2,000 to 5,000.

Based on the results above, the method would involve using three and four spaghetti strands. The glutograph would be configured with weight and with 3,000 and 4,000 impulses. Impulse effect seemed to be less than strand effect. Three strands were good for stretch time and four strands were good for strain values.

Table 6. Analysis of variance for glutograph configured with weight for strain, stretch time, and percent recovery of spaghetti containing nontraditional ingredients tested with 3 strands and 1,000 to 5,000 impulses.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	5	238,503	8.06	<0.0001
	Impulse	4	67,350	3.19	0.0352
	Error a (Impulse*rep)	20	21,119	0.71	0.8098
	Ingredient	8	370,534	12.52	<0.0001
	Impulse*Ingredient	32	33,378	1.14	0.2907
	Error b	200	29,594		
Stretch Time	Rep	5	18,856	20.65	<0.0001
	Impulse	4	1,380	3.72	0.0203
	Error a (Impulse*rep)	20	371	0.41	0.9895
	Ingredient	8	27,603	30.23	<0.0001
	Impulse*Ingredient	32	844	0.92	0.5885
	Error b	200	913		
Percent recovery	Rep	5	795	4.3	0.001
	Impulse	4	6,084	57.1	<0.0001
	Error a (Impulse*rep)	20	107	0.58	0.9257
	Ingredient	8	1,564	8.47	<0.0001
	Impulse*Ingredient	32	223	1.21	0.2198
	Error b	200	185		

Table 7. Mean strain, stretch time, and percent recovery (averaged over impulse) for spaghetti made with different ingredients tested with glutograph configured with weight.

Ingredient	Stretch Time, sec	Strain, BU	Percent Recovery
Ultragrain (U)	89.8 a	569 d	32.6 a
U + Fine Flaxseed Flour (FF)	84.5 a	636 d	15.6 bc
Semolina (S) + U	76.3 a	643 d	18.7 b
S + FF	48.6 b	766 c	14.1 bcd
Semolina	45.7 b	787 bc	19.3 b
S + U + FF	45.3 b	780 bc	12.4 bcd
U + Coarse Flaxseed Flour (CF)	15.7 c	864 ab	8.2 d
S + CF	13.7 c	838 a-c	13.1 bcd
S + U + CF	12.6 c	886 a	9.8 cd

Table 8. Mean strain, stretch time, and percent recovery (averaged over ingredients) for spaghetti made with glutograph configured with different impulses and with weight.

Impulse	Stretch Time, sec	Strain, BU	Percent Recovery
1000	40.7 c	768 ab	33.8 a
2000	50.6 ab	745 b	16.3 b
3000	49.6 ab	728 b	13.3 bc
4000	53.8 a	715 b	9.7 cd
5000	45.4 bc	804 a	6.7 d

Validation of Method

Spaghetti Samples (2011 drill strip)

Spaghetti sample main effect was significant for stretch time, strain, and percent recovery (Table 9). Stretch time ranged from a low of 10.3 sec (sample 3050) and 10.5 sec (sample 3061) to a high of 51.8 sec (sample 3158) as shown on Table 10. These values are similar to those of previous experiment (Figure 10) where three strands resulted in stretch times below 50 sec. All samples resulted in strain values above 800, which was the stop point for determining stretch time. Previous experiments also resulted in strain samples above 800 when running the test with three strands (Figure 9, Tables 4 and 5). The percent recovery ranged from a low of 9.4 and

9.6% (sample 3057 and 3050, respectively) to 13.5% (sample 3158). Percent recovery tends to be greater with four than with three strands.

Impulse main effect was significant for percent recovery (Table 9). Stretch time and strain were not affected by impulse. Percent recovery was greater with 3,000 impulse (13.1%) than for 4,000 impulse (9.8%).

Textural properties of cooked spaghetti samples were determined using Pasta blade (firmness and peak force) and the Ottawa cell (hardness, springiness, cohesiveness, gumminess, and chewiness) (Table 11). Cooked spaghetti samples differed in firmness and peak force required to cut the strands with the Pasta blade. Both firmness and peak force were greatest for sample 3158 and least for sample 3050. Similarly, the Ottawa cell detected differences among spaghetti samples in hardness, cohesiveness, and gumminess (Table 11). Hardness and gumminess were greatest for sample 3158 and least for sample 3050, while cohesiveness was greatest for sample 3174 and least for sample 3100. Differences among samples were not detected for springiness or for chewiness.

Pearson correlation coefficients were determined for glutograph parameters and Pasta blade parameters and for glutograph parameters and Ottawa cell parameters (Table 12). Stretch time reflects the resistance to turning the plate; more resistance the longer the stretch time. Stretch time was positively correlated with firmness (r=0.84; p=0.005); peak force (r=0.81; p=0.009); hardness (r=0.82; p=0.007); and gumminess (0.84; p=0.005). A low strain value would indicate resistance to turning the plate. Strain was negatively correlated with peak force (r=-0.67; p=0.047). So, lower the strain number the greater the peak force. Percent recovery reflects elasticity. Percent recovery was positively correlated with peak force (0.82; p=0.007).

Thus, samples with a high percent recovery, more elastic, would require a high peak force to cut through spaghetti strands.

Table 9. Analysis of variance for glutograph configured with weight for strain, stretch time, and percent recovery of spaghetti tested with 3 strands and 3,000 and 4,000 impulses.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	6	2,863	4.63	0.0004
	Impulse	1	120	0.11	0.7549
	Error a (Impulse*rep)	6	1,120	1.81	0.1049
	Spaghetti samples (SS)	8	3,062	4.95	<0.0001
	Impulse*SS	8	739	1.2	0.3101
	Error b	96	618		
Stretch Time	Rep	6	1,306	4.44	0.0005
	Impulse	1	427	0.99	0.3584
	Error a (Impulse*rep)	6	431	1.47	0.1978
	Spaghetti samples (SS)	8	2,683	9.11	<0.0001
	Impulse*SS	8	317	1.08	0.387
	Error b	96	294		
Percent recovery	Rep	6	1	1.01	0.4218
	Impulse	1	356	98.9	0.0001
	Error a (Impulse*rep)	6	4	2.65	0.0203
	Spaghetti samples (SS)	8	34	25.34	<0.0001
	Impulse*SS	8	1	0.9	0.5215
	Error b	96	1		

Table 10. Mean strain, stretch time, and percent recovery (averaged over impulses) for spaghetti samples tested with glutograph configured with weight.

Spaghetti samples	Stretch Time, sec	Strain, BU	Percent Recovery
3050	10.3 d	831 bc	9.6 e
3051	20.6 cd	831 bc	10.7 cd
3057	23.9 c	845 ab	9.4 e
3061	10.5 d	851 a	10.3 de
3093	19.4 cd	831 bc	12.3 b
3095	19.2 cd	824 cd	12.9 ab
3100	41.3 ab	813 cd	11.2 c
3158	51.8 a	807 d	13.5 a
3174	31.4 bc	814 cd	13.2 ab

Table 11. Mean values for texture of cooked pasta determined using Pasta blade and an Ottawa cell probe.

	Pasta blade		Ottawa cell				
Spaghetti samples	Firm-ness	Peak force	Hard-ness	Springi-ness	Cohesive-ness	Gummi-ness	Chewi-ness
3050	4.7 f	281 d	14,099 e	0.741 a	0.750 ab	10,551 f	7,828 a
3051	5.3 de	307 cd	15,254 cd	0.788 a	0.735 ab	11,245 de	8,891 a
3057	6.0 b	326 bcd	16,430 ab	0.758 a	0.745 ab	12,184 b	9,281 a
3061	5.2 e	324 bcd	14,800 de	0.801 a	0.744 ab	11,017 e	8,859 a
3093	5.2 ef	336 bc	14,865 de	0.763 a	0.744 ab	11,045 e	8,449 a
3095	5.8 bcd	373 ab	15,049 cd	0.776 a	0.750 ab	11,271 de	8,784 a
3100	5.9 bc	358 b	15,900 bc	0.749 a	0.728 b	11,558 cd	8,668 a
3158	6.6 a	417 a	16,814 a	0.716 a	0.762 ab	12,833 a	9,200 a
3174	5.5 cde	357 b	15,236 cd	0.831 a	0.775 a	11,814 bc	9,811 a

Table 12. Pearson correlation coefficient (r) for glutograph parameters and Pasta blade and Ottawa cell textural data for cooked spaghetti samples.

	Pasta blade		Ottawa cell				
Variable	Force	Firm-ness	Hard-ness	Springi-ness	Cohesive-ness	Gummi-ness	Chewi-ness
Stretch time	0.806[a] 0.009[b]	0.840 0.005	0.819 0.007	-0.389 0.300	0.209 0.590	0.836 0.005	0.477 0.195
Strain	-0.674 0.047	-0.479 0.192	-0.358 0.344	0.254 0.510	-0.348 0.358	-0.455 0.219	-0.220 0.570
Percent Recovery	0.820 0.007	0.443 0.232	0.245 0.526	0.077 0.844	0.558 0.118	0.422 0.258	0.426 0.253

[a]Pearson correlation coefficient
[b]*p* value

Nontraditional Pasta

Impulse by ingredient interaction was significant for strain (Table 13). For all ingredients, strain was greater with 3,000 impulse than with 4,000 impulse, except for semolina-FF10% and semolina-Oat20% where strain value was similar with 3,000 and 4,000 impulse as shown on Table 14. Strain value with soy 10% and soy at 20% was substantially lower than strain with other ingredients with 3,000 and 4,000 impulse. Additionally, with 4,000 impulse strain value for the SWW formulation was also low relative to the other formulations. Low strain values are associated with resistance to turning the plate.

Impulse by ingredient interaction was significant for stretch time (Table 13). In general, stretch time was greatest with WW, SWW, SSoy10, SSoy20; intermediate with SOat10 and SOat20; and least with S, SFF10, and SFF20 (Table 14). Stretch time was greater with 4,000 than with 3,000 impulses for semolina, SFF20, SOat10 and SWW, but were similar for SFF10, SOat20, SSoy10, Ssoy20. At 3,000 impulse, stretch time was greatest with SSoy10 and SSoy20; intermediate with SFF10, SOat10, SOat20, SWW; and least with semolina and SFF20. At 4,000 impulse, stretch time was greatest with SOat10, SSoy10, SSoy20, SWW; intermediate with semolina, SFF20, SOat20; and least with SFF10. Ranking did vary with impulse but generally spaghetti with soy had long stretch times.

Impulse by ingredient interaction was significant for percent recovery (Table 13). In general, percent recovery was greatest with SSoy10 and SSoy20 and least with semolina, SFF10, SFF20, and SOat20 (Table 14).

Textural properties of cooked spaghetti samples were determined using Pasta blade (firmness and peak force) and the Ottawa cell (hardness, springiness, cohesiveness, gumminess, and chewiness) (Table 15). Cooked spaghetti samples differed in firmness and peak force required to cut the strands with the Pasta blade. Both firmness and peak force were greatest for SSoy10 and SSoy20 and least with SFF10, SFF20. Similarly, values for hardness, springiness, cohesiveness, gumminess, and chewiness determined by the Ottawa cell detected differences among the spaghetti samples. Hardness was greatest with Soy20 and WW and least with semolina, SFF10 and SOat10. Springiness was greatest with semolina and SWW and least with WW. Cohesiveness was greatest with semolina and least with SFF20. Gumminess was greatest with SSoy20 and least with SFF20. Small differences in chewiness were detected among the samples.

Pearson correlation coefficients were determined for glutograph parameters and Pasta blade parameters and for glutograph parameters and Ottawa cell parameters (Table 16). Stretch time with 3,000 impulse was positively correlated with firmness and peak force and stretch time with 3,000, 4,000 impulse were positively correlated with hardness and gumminess. Strain with 3,000 and 4,000 impulse was negatively correlated with peak force, firmness, hardness and gumminess. Percent recovery was positively correlated with peak force, firmness, hardness, and gumminess. Stretch time, strain, and percent recovery did not correlate with springiness, cohesiveness or chewiness.

Table 13. Analysis of variance for glutograph configured with weight for strain, stretch time, and percent recovery of spaghetti containing nontraditional ingredients tested with 3 strands and 3,000 and 4,000 impulses.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	2	10,340	0.83	0.4384
	Impulse	1	1,094,771	62.31	0.0157
	Error a (Impulse*rep)	2	17,569	1.41	0.2474
	Ingredient	8	1,414,208	113.26	<0.0001
	Impulse*Ingredient	8	132,832	10.64	<0.0001
	Error b	194	12,487		
Stretch Time	Rep	2	38	0.09	0.9181
	Impulse	1	28,820	32.96	0.029
	Error a (Impulse*rep)	2	874	1.95	0.1449
	Ingredient	8	17,316	38.64	<0.0001
	Impulse*Ingredient	8	4,168	9.3	<0.0001
	Error b	194	448		
Percent recovery	Rep	2	4	0.11	0.8962
	Impulse	1	213	1.62	0.3307
	Error a (Impulse*rep)	2	131	3.88	0.0222
	Ingredient	8	1,955	57.76	<0.0001
	Impulse*Ingredient	8	94	2.78	0.0063
	Error b	194	34		

Table 14. Mean values for impulse by ingredient interaction for stretch time and strain for spaghetti containing nontraditional ingredients tested with glutograph configured with weight.

	Impulse				
	3,000	4,000	3,000	4,000	
Ingredients	Stretch time, sec		Strain, BU		Percent Recovery
Semolina (S)	23.3 f A	84.0 bc B	810.4 ab A	749.6 a-c B	9.6 cd
S + Flaxseed flour 10%	48.7 c-e A	50.3 cd B	802.8 a-c A	805.5 a B	8.6 d
S + FF 20%	20.9 f A	75.7 b-d B	815.7 a A	718.4 a-d B	8.8 d
S + Oat flour (Oat) 10%	61.8 a-e A	109.5 b B	792.1 a-d A	588.8 a-e B	12.4 c
S + Oat 20%	87.7 a-d A	79.3 b-d B	735.7 a-e A	753.9 ab B	8.5 d
S + Soy flour (Soy) 10%	114.0 a A	114.0 a B	345.9 f A	221.0 f B	20.2 b
S + Soy 20%	114.0 abA	114.0 a B	181.9 f A	119.4 f B	36.3 a
S + Whole wheat (WW) 51%	86.5 a-e A	114.0 a B	707.6 a-e A	355.1 ef B	12.5 c
WW	89.9 a-c A	114.0 a B	599.8 a-e A	198.5 f B	17.6 b

Table 15. Mean values for texture of cooked pasta containing nontraditional ingredients determined using Pasta blade and an Ottawa cell probe.

	Pasta blade		Ottawa cell				
Ingredients	Firm-ness	Peak force	Hardness	Springi-ness	Cohesive-ness	Gummi-ness	Chewi-ness
Semolina (S)	4.6 de	262 d	17,583 e	0.760 a	0.729 a	12,797 cd	9,758 a
S + Flaxseed Flour (FF) 10%	4.6 de	241f	17,505 e	0.706 abc	0.679 cd	11,878 d	8,430 ab
S + FF 20%	4.4 e	244 ef	18,088 de	0.640 bcd	0.646 e	11,649 d	7,496 b
S + Oat Flour 10%	5.3 c	281 c	17,843 e	0.724 ab	0.710 ab	12,676 cd	9,183 ab
S + Oat Flour 20%	5.0 c	264 d	18,643 cde	0.735 ab	0.694 bc	12,956 cd	9,555 a
S + Soy Flour 10%	6.0 b	313 b	20,226 bc	0.675 a-d	0.710 ab	14,306 ab	9,665 a
S + Soy Flour 20%	6.5 a	337 a	22,102 a	0.624 cd	0.691 bc	15,328 a	9,673 a
Whole Wheat (WW)	4.9 cd	262 d	21,239 ab	0.598 d	0.653 de	13,870 bc	8,419 ab
S + WW 49 + 51%	5.0 c	259 de	19,546 cd	0.743 a	0.682 c	13,320 bc	9,958 a

Table 16. Pearson correlation coefficient (r) for glutograph parameters and Pasta blade and Ottawa cell for cooked spaghetti containing nontraditional ingredients.

Variable	Pasta blade	Ottawa cell					
	Force	Firmness	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness
Stretch time mean	0.7595[a] 0.0176[b]	0.8286 0.0058	0.8445 0.042	-0.3279 0.389	0.1087 0.7807	0.8922 0.012	0.5412 0.1327
Stretch time 3,000 impulse	0.7256 0.0269	0.8253 0.0062	0.8158 0.0073	-0.3167 0.4064	0.0741 0.8498	0.8546 0.0033	0.5121 0.1587
Stretch time 4,000 impulse	0.6494 0.0584	0.6579 0.0541	0.7106 0.0319	-0.2784 0.4683	0.1353 0.7286	0.7605 0.0174	0.4674 0.2045
Strain mean	-0.8390 0.0047	-0.8783 0.0018	-0.9458 0.0001	0.5902 0.0943	0.0108 0.9781	-0.9429 0.0001	-0.3506 0.3549
Strain 3,000 impulse	-0.9104 0.0006	-0.9347 0.0002	-0.8734 0.0021	0.5393 0.1340	-0.0969 0.8042	-0.9249 0.0004	-0.3721 0.3241
Strain 4,000 impulse	-0.7185 0.0292	-0.7674 0.0158	-0.9370 0.0002	0.5897 0.7987	0.0997 0.7987	-0.8891 0.0013	-0.3070 0.4217
Percent recovery mean	0.8934 0.0012	0.8994 0.0010	0.8667 0.0025	-0.5756 0.1048	0.0550 0.8882	0.9012 0.0009	0.3154 0.4084
Percent recovery 3,000 impulse	0.8886 0.0014	0.8785 0.0018	0.7895 0.0114	-0.5221 0.1494	0.1095 0.7791	0.8510 0.0036	0.3145 0.4098
Percent recovery 4,000 impulse	0.8717 0.0022	0.8895 0.0013	0.9022 0.0009	-0.6018 0.0864	0.0108 0.9781	0.9145 0.0006	0.3062 0.4229

[a]Pearson correlation coefficient.
[b]*p* value.

CONCLUSION

This study demonstrates that the glutograph has the capability of detecting differences among spaghetti samples that differed in the cultivar origin of the semolina used to make the spaghetti and in spaghetti samples that differed in ingredient formulation. Results indicated that using three strands, with weight and with 3,000 and 4,000 impulses resulted in the most noticeable differentiation of spaghetti samples. Impulse effect seemed to be less significance than strand effect. Three strands were good for stretch time and four strands were good for strain values.

Glutograph instrument has potential to be used to evaluate gluten quality and functional properties of pasta. The glutograph parameters studied in this research might provide useful in rapid quality tests for gluten strength and texture of cooked pasta because this method is relatively easy and is not time consuming.

FUTURE RESEARCH AND APPLICATIONS

For future research, sensory analysis can be carried out to further correlate the findings from this study.

Texture analyzer is more commonly used for long goods. It is more challenging to use Pasta blade on short goods due to their unconventional shapes. In this study, long good pasta (spaghetti) was used. To better understand the functionality of glutograph, future research should include short goods pasta such as shells and macaroni. Adding another piece of instrument for rheology testing instead of a more traditional texture analyzer would be very advantageous for future texture analysis applications.

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APPENDIX

Table A1. Analysis of variance for glutograph configured with and without weight for strain, stretch time, and percent recovery of spaghetti tested with 1-6 strands and 1,000 to 10,000 impulses, averaged over cooking time.

Variable	Source	df	MS	F value	Pr>F
Strain	Rep	2	783	0.22	0.8046
	Weight (WT)	1	787,083	81.87	0.012
	Error a (WT*rep)	2	9,614	2.67	0.0715
	Impulse	9	276,312	57.36	<0.0001
	WT*Impulse	9	6,405	1.33	0.2565
	Error b (WT*Impulse*rep)	36	4,817	1.34	0.1082
	Strand	5	7,990,649	2,221.89	<0.0001
	WT*Strand	5	239,812	66.68	<0.0001
	Impulse*Strand	45	42,864	11.92	<0.0001
	WT*Impulse*Strand	45	8,572	2.38	<0.0001
	Error c	200	3,596		
Stretch Time	Rep	2	9	0.41	0.6674
	Weight (WT)	1	7,256	122.37	0.0081
	Error a (WT*rep)	2	59	2.58	0.0786
	Impulse	9	23,124	1,105.92	<0.0001
	WT*Impulse	9	562	26.9	<0.0001
	Error b (WT*Impulse*rep)	36	21	0.91	0.6219
	Strand	5	78,130	3,394.47	<0.0001
	WT*Strand	5	5,954	258.68	<0.0001
	Impulse*Strand	45	5,582	252.59	<0.0001
	WT*Impulse*Strand	45	462	20.06	<0.0001
	Error c	200	23		
Percent recovery	Rep	2	1	0.03	0.9674
	Weight (WT)	1	12.642	59.59	0.0164
	Error a (WT*rep)	2	212	7.26	0.0009
	Impulse	9	658	13.15	<0.0001
	WT*Impulse	9	10	0.19	0.9933
	Error b (WT*Impulse*rep)	36	50	1.71	0.0111
	Strand	5	125,962	4,312.13	<0.0001
	WT*Strand	5	7,007	239.88	<0.0001
	Impulse*Strand	45	167	5.71	<0.0001
	WT*Impulse*Strand	45	28	0.97	0.5326
	Error c	200	29		