ABSTRACT

THE EFFECTS OF THERMAL PROCESSING ON PROPERTIES OF FUNDAMENTAL FOOD POLYMERS IN COMMERCIAL ASIAN AND EXPERIMENTAL SORGHUM NOODLES

(April 1999)

Michelle Rene Leach, University Undergraduate Research Fellow

Processing variables of 100% sorghum noodles were evaluated. A dough was made, extruded to create noodles then dried

Structural, physical, and cooking characteristics of the experimental sorghum noodles, as well as thin spaghetti, commercial Asian rice, broad bean, tapioca, sweet potato and egg noodles were evaluated. In comparison to the commercial noodles, the experimental sorghum noodles had high dry matter loss, but similar water uptake and moisture. The dry matter loss of sorghum noodles was greatly affected by the heating stage before extrusion, with a lower dry matter loss resulting from a longer heating time.

The internal structure of the noodles was evaluated with the ESEM. Starch noodles had a thick starchy continuous phase that was smooth and amorphous. The protein based noodles were held together by a gluten matrix, small endosperm pieces with intact starch granules were visible and suspended within the matrix. Noodles made from any grain or starch other than wheat must rely on starch gelatinization for their structure.

The sorghum noodles produced in this experiment indicated that sorghum could be used to produce a non-wheat noodle. A sorghum noodle could be a new food product for those who are gluten-intolerant or an alternative food product for the semi-arid tropic regions where sorghum is a native grain.

THE EFFECTS OF THERMAL PROCESSING ON PROPERTIES OF FUNDAMENTAL FOOD POLYMERS IN COMMERCIAL ASIAN AND EXPERIMENTAL SORGHUM NOODLES

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Submitted to the
Office of Honors Programs and Academic Scholarships
Texas A&M University
in partial fulfillment of the requirements for

1998-99 UNIVERSITY UNDERGRADUATE RESEARCH FELLOWS PROGRAM

April 14, 1999

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Processing variables of 100% sorghum noodles were evaluated to determine the effect on noodle quality. A dough was created by microwave heating a flour (100g) with 1% salt and water (90ml). The optimum cooking time was determined. The dough was put through a forming extruder to create noodles then dried under controlled environmental conditions. The noodles were smooth and straight when uncooked and maintained their firmness during cooking.

Structural, physical, and cooking characteristics of the experimental sorghum noodles, as well as thin spaghetti, commercial Asian rice, broad bean, tapioca, sweet potato and egg noodles were evaluated. Fracturability of the dry noodles and firmness of the cooked noodles was measured, along with water uptake during cooking and dry matter losses. The three non-cereal starch noodles had low dry matter loss. The experimental sorghum noodles had high dry matter loss, but comparable water uptake and moisture. The dry matter loss of the sorghum noodles was greatly affected by the dough heating stage before extrusion, with a lower dry matter loss resulting from a longer heating time.

The internal structure of the commercial noodles, evaluated with ESEM, was consistent in that there were few or no air spaces in the interior. The starch noodles had a thick starchy continuous phase that was smooth and amorphous; occasionally, starch granules were visible within the matrix. The protein based noodles were held together by a gluten matrix and small endosperm pieces with intact starch granules were visible and suspended within the matrix.

Noodles made from any grain or starch other than wheat must rely on starch gelatinization for their structure. The degree of starch modification in the noodle can be deduced from the RVA pasting curves. The starch in wheat noodles is less modified due to the noodle strength provided by the gluten, as evident in the RVA curve. The effect of heating time on the sorghum noodle starch is also evident in the RVA curves. The longer the dough was heated, the lower the peak viscosity. Drying conditions had little effect on the pasting curve.

The sorghum noodles produced in this experiment indicated that sorghum could be used to produce a non-wheat noodle. A sorghum noodle could be a new food product for those who are gluten-intolerant. It could also be an alternative food product for the semi-arid tropic regions where sorghum is a native grain.

DEDICATION

To my parents:

For Mom and Dad who stand behind me in everything and encourage me to reach for the stars. You are the wind beneath my wings.

To Dr. Rooney:

Whose support has taught me that it is okay to make mistakes, as long as you see them as 'scar tissue' and keep on trying. I am so grateful for everything you have done to help me during my time at Texas A&M.

ACKNOWLEDGEMENTS

I could not have done any of this without the constant help and support of Dr. Elly Suhendro. She kept an open door and assisted me whenever I had a question or problem (which was often). Dr. Lloyd Rooney's encouragement kept me motivated and challenged throughout the duration of this project. Dr. Cassandra McDonough was always available to help me and to answer my questions.

Thanks to the members of the Cereal Quality Laboratory who made everyday fun and provided laughter and smiles.

Thanks to my friends and W.I.L. group at A&M who patiently listened to my 'noodle stories' and helped me stay focused.

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CHAPTER I

INTRODUCTION

Noodles play an important role in the diets of many of the worlds population, especially Japan and China. Numerous types of noodles exist, varying in raw materials, product shape, processing methods and intended market (Nagao 1996). A noodle made from durum wheat is called pasta. Pasta's structure relies on the gluten protein complex formed by the mixing of wheat flour and water (Morris and Rose 1996). As wheat is the only grain to form gluten, a non-wheat-based noodle must rely on the gelatinization of starch for its structure. Starch based noodles are popular throughout the Pacific Rim countries and are used in oriental dishes in other countries (Kunitz 1997, Kim et al 1996).

Sorghum is a grain used for both human food and animal feed. It is the leading cereal grain in Africa and is important also in India, China and the United States. It grows best in warm conditions and is very resistant to drought and heat (US Feed Grains Council 1998). Sorghum is mainly grown where other crops cannot compete, namely the semi-arid tropic regions. In the US, livestock feed accounts for 97% or more of the domestic sorghum usage.

Creating a satisfactory noodle from sorghum grain would create an alternative food source that utilizes a native grain and minimizes the amount of imported grain (Kunitz 1997). In the United states, where ample amounts of wheat is grown, the noodle could be a product for individuals suffering from gluten intolerance, celiac sprue, a condition that affects about 10 million people in the US (Sosland 1998).

This thesis follows the style and format of Cereal Chemistry

Objectives of Study

General Objective

The processing conditions required to produce noodles from 100% sorghum flour will be investigated, as well as a characterization of commercial noodles.

Specific Objectives

1. Characterize commercially available noodles (spaghetti, egg noodles, broad bean, rice, tapioca and sweet potato) to compare to the sorghum noodles made experimentally.
2. Study the changes encountered in the starch at critical phases in the noodle making process
3. Study the effect of drying conditions on noodle quality.
4. Study the effect of pre-extrusion heating methods on noodle quality.

CHAPTER II

LITERATURE REVIEW

Pasta

Pasta is comprised of extruded dough pieces that are usually dried during production. It is prepared from durum (*Triticum turgidium* var. *durum*) semolina. Semolina is the primary product of durum wheat milling; it is larger sized pieces of endosperm. It is commonly defined as the fraction retained on a US no. 100 sieve.

A high level of strong gluten is preferred. The protein must form a continuous matrix to entrap the starch granules so that the pasta surface does not become sticky during cooking. (Morris and Rose 1996)

Gluten completely surrounds the starch granules (Feillet 1984). The viscoelasticity of gluten restricts starch swelling and cohesion of gluten prevents leaching during gelatinization in the cooking step.

Asian wheat noodles

Wheat flour noodles are an important part in the diet of much of Asia. The amount of flour used for noodle making in Asia accounts for about 40% of the total flour consumed. (Hou and Kruk 1998). Noodle use runs parallel to bread consumption in the West; they are the traditional form in which wheat is consumed. (Morris and Rose 1996)

Asian noodles are different from pasta products in the ingredients used, the processes involved and the consumption patterns. They are characterized by thin strips made from sheeted dough that has been made from flour of both hard and soft wheat, water and salt. Eggs can also be added to give a firmer texture. (Hou and Kruk 1998).

Wheat flour (three parts) is mixed with salt or alkaline salt (one part) to make a dough. The dough is compressed between a series of rolls to form a dough sheet. The gluten network is developed during the sheeting process. After sheeting, the dough is slit into noodles. (Hou and Kruk 1998).

Non-wheat noodles

Noodles made from gluten-free starch materials must rely on the gelatinization of starch for their structure. This is usually done by one or two heat treatments during processing. Commercial noodles are made from high amylose genotypes, which exhibit a high rate of retrogradation (Mestres et al. 1988).

Noodles made from starch are widely consumed in East Asia. The are sometimes called glass noodles because of their characteristic glossy, transparent appearance when cooked (Kim and Wiesenborn 1996). Mung bean starch is usually the primary ingredient in glass noodles because it gives the desired texture and appearance. Legume starch pastes are more viscous than those of cereal starches, and have a higher resistance to swelling and rupture than cereal starches (Singh et al. 1989).

The starch structure of the starch noodle is described as a ramified three-dimensional network that is inter-linked by amylose-based crystallites (Mestres et al. 1988). This structure supports why gluten-free noodles are made with high amylose starches (Lii and Chang, 1981). The amylose network system swells in boiling water when the noodle is cooked. Cooking losses are based on the degradation of the amylose network under swelling forces (Mestres et. al 1988).

Sorghum noodles were made by Lekalake (1993) and Kunitz (1997). The method studied by Lekalake involved the production of a dough ball of flour and water being cooked in excess boiling water before being extruded into noodles. The extruded noodles were surface gelatinized by boiling water, cooled and dried in a forced air oven. The Kunitz method involved heating the dough by microwave or hot-plate before extrusion. The extruded noodles were dried under environmentally controlled conditions in a two-step method.

In the production of rice noodles, the entire kernel is used, not just the endosperm. The whole rice is wet milled and ground into a paste or rice dough. The dough is steamed and extruded, then aged. The aged dough is sheeted or extruded a second time to form the final noodle shape, and cooked in boiling water or steam cooked (Kohlwey et al 1995). The degree of gelatinization of the rice starch before and after extrusion is critical. The gelatinization is required to allow the starch to act as a binder during extrusion. However, excessive gelatinization can cause extremely high extrusion pressures (Lekalake 1993, Kunetz 1997, Kohlwey et al 1995).

Measurement of Noodle Cooking Quality

Several physical tests were established for measurement of noodle quality. Optimum cooking time is the time required until the center core of the pasta can no longer be seen after the noodle is crushed between two glass plates (AACC 1995). Cooking losses were determined as the total amount of soluble and insoluble pasta-derived matter left in the cooking water after the noodles were removed. The weight of the noodle after cooking is considered to be the yield of food for consumption (Abecassis et al 1989, Kunitz 1997). Kim et al (1996) determined cooking quality by cooked weight and cooking loss. Cooking losses for starch noodles should be less than 10%.

Viscoanalysis of Noodles and Flours

Starch pasting characteristics play an important role in determining flour and noodle quality. The ratio of amylose to amylopectin content determines a starch's pasting characteristics.

Starch swelling power has been a good predictor of wheat quality for Japanese noodles. High pasting viscosity, measured with the Rapid-Visco Analyzer (RVA) has been characteristic of starch from wheat with good Japanese noodle-making potential (Crosbie 1991).

Whalen (1999) did research using different RVA profiles to differentiate between pasta products dried under different conditions. The standard RVA profile showed no difference, but a critical paste profile showed a large difference. A critical paste profile was one that has a long, slow increase in temperature with a high solids level.

The operating conditions of the RVA can have an effect on both the actual value measured for the pasting viscosity and the ability to use those values for predicting noodle quality. Long heating times tended to give paste viscosities with the highest correlation with noodle quality (Batey et al 1997)

Starch swelling volume gave a high correlation with noodle quality. Flour swelling volume gives high correlation as well, but not as high as isolated starch (Crosbie 1991). However, starch isolation is a long, intensive process and as such, would be an unsatisfactory test in the screening of a large number of samples (Batey et al. 1997).

Sorghum Structure and Uses

Sorghum bicolor L. Moench constitutes a major source of calories and protein for millions of people in Africa and Asia (Rooney 1996). It is consumed as a food grain in the Middle East, India and Africa, while being used as animal feed in the United States (Sosland 1998).

In 1994, sorghum ranked fifth among the most important cereal crops of the world after wheat, rice, maize and barley. Eighty percent of the area devoted to sorghum is located within Africa and Asia (Dahlberg 1998).

Sorghum kernels are spherical, ranging in weight from 20 – 30 mg (Hoseney 1994). The kernel is composed for the pericarp (outer covering), endosperm (storage tissue), and germ (embryo) (Rooney 1996). The pericarp can be divided into epicarp, mesocarp and endocarp. Sorghum is the only cereal to have significant amounts of starch in the mesocarp (Rooney 1996). The endosperm characteristics of the sorghum grain can have an effect of the processing. The sorghum endosperm can be identified as hard or soft, referring to the association of the starch and protein matrix (Hoseney 1994). The stronger the association, the harder the endosperm. Work done by Lekalake in 1993 found that sorghums of intermediate to hard endosperm produced better noodles than sorghums of soft endosperm texture (Lekalake 1993).

Starch, cellulose, simple sugars and pentosans make up 80% of the dry weight of the kernel. Starch makes up 70-80% of that amount (depending on the cultivar). Sorghum starch is normally 70% amylopectin and 30% amylose (Lekalake 1993).

The areas where sorghum is used as a food grain are very arid parts of the world where rice and wheat cannot grow. It can be dry milled into grits and meals used for brewing, baking, snack foods and other uses. It can be malted to produce beer and breakfast foods. (Rooney 1996, Sosland 1998).

Early varieties of sorghum had a bitter taste, due to the presence of phenolic acid and tannins. New white varieties of white sorghum have completely eliminated the phenolic acid and bitter taste. One advantage of the bland flavor of white sorghum is that it can be added in small amounts to products without affecting the taste or texture. Low sorghum prices could lower the overall cost of producing the product to which it is added. There is a special market in multi-grain products (Sosland 1998).

Food Polymers

Food is composed of a variety of different chemical components. The three major polymers seen in food are proteins, lipids and polysaccharides.

Protein is a polymer made up of amino acids. The amino acids are linked in a specific sequence by peptide bonds. The unique sequence of amino acids (known as the primary sequence of a protein) determines the functionality and attributes of each protein (Boyer 1999).

Cereal proteins are classified into groups based on their solubility in a series of solvents. Water-soluble proteins are called albumins, dilute aqueous salt soluble proteins are called globulins; alcohol/water mixture soluble proteins are called prolamins and dilute acid or alkali soluble proteins are called glutelins. (Shewry 1996). The starchy endosperm of cereal grains is the location of most of the cereal's protein. The prolamins and glutelins are the major storage protein of most cereals.

Polysaccharides (carbohydrates) can exist as starch, cellulose, chitin or glycogen (Boyer 1999). Carbohydrates are quantitatively the major component of a cereal grain. Cereal carbohydrates consist of the cellulose found in the cell walls and the starch granules. Cereal grains store energy in the form of starch, which is found in granules (Hoseney 1994). Starch is an association of two polysaccharides, amylose and amylopectin. Amylopectin usually composes 70-80% of the starch, with amylose comprising the remaining 20-30%. A table comparing the two polysaccharides is below (Stone 1996).

	Amylose	**Amylopectin**
Monomer residue	α-D-glucopyranosyl	α-D-glucopyranosyl
Linkage type	Interchain (1→4) (98-99%) Branch Point (1→6) (1%)	Interchain (1→4) (95%) Branch Point (1→6) (5%)
Organization	Long linear chains	Branch on branch
Molecular Weight	10^5-10^6	$>10^8$
Degree of Polymerization	$1.5\text{-}6.3 \times 10^3$	$10^4 – 10^7$
Retrogradation Tendency	High	Low

When starch is heated in water, the water freely penetrates the granule. The granule swells slightly and can hold about 30% of its dry weight at moisture. The volume change and water absorption are reversible and no changes will be seen by heating the starch-water system to just below its gelatinization temperature. Gelatinization is defined as the irreversible loss of birefringence (birefringence is the ability of starch molecules to rotate plane-polarized light when viewed under a microscope) (Hoseney 1994). When starch is gelatinized, the granule becomes irreversibly distorted and a large increase in viscosity is noted. Amylose is solubilized. The resulting structure is a fluid composed of porous, gelatinized and swollen starch granules with an amylopectin skeleton, suspended in a hot amylose solution (Stone 1996).

Lipids represent approximately 3% of the whole cereal grain and decrease to almost half this level after milling (Fujino et al 1996). They can be categorized based on their chain structure: straight or branched.

CHAPTER III

MATERIALS AND METHODS

Raw Materials

White food grade sorghum, Tx631*Tx 436, grown under irrigation at the Texas A&M Experimental Station at Halfway, TX was used.

Sample Preparation

Sorghum Decortication

Sorghum kernels were decorticated with an abrasive dehuller (PRL Mini-Dehuller, Nutana Machine Co., Saskatoon, Canada) until 10% removal of pericarp. Bran was separated from the decorticated kernels using the Carter Dockage Tester (Model XT1 207, Hart-Carter Co., Minneapolis, MN) equipped with a No.2 screen.

Sorghum Flour Production

The sorghum was milled by a two-step process. (Figure 1) Decorticated kernels were passed through a Fitz Mill Hammermill (model D, Fitzpatrick Co., Elmhurst, IL) then passed through the break and reduction roll system of the Brabender Quadrumat Senior Mill (CW Brabender Instruments, Inc., South Hackensack, NJ).

Noodle Production Process

Noodle Preparation

Noodles preparation method (Figure 2) involved adding 90ml of distilled water to 100g of sorghum flour and 1 g of salt. The flour water mixture was pressed along the side of a Pyrex bowl (Corning Glass Works, Co., Corning, NY)

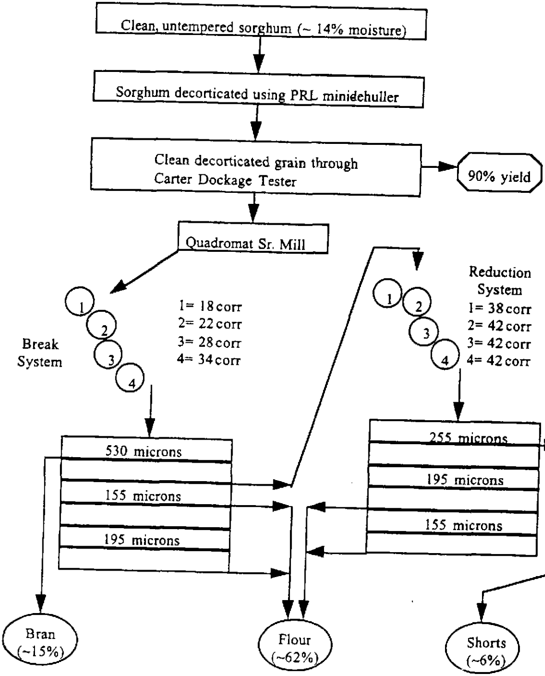


Fig. 1. Milling of sorghum flour.

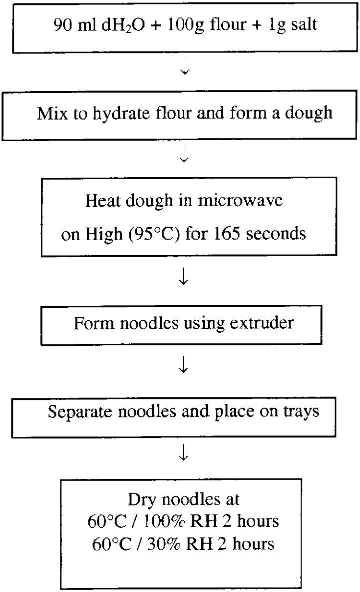


Figure 2 – Flow diagram for preparation of noodles

to ensure uniform heating. The mixture was heated to 95° on high power for 45 seconds, stirred, then heated for 30, 45, 60 or 90 seconds in a microwave (Kenmore Model N721.89660590, Sears, Robuck and Co., Hoffman Estates, IL). The heated mixture was passed through a forming extruder to produce noodles (Hobart Mixer, Model N-50, Hobart Manufacturing Co., Troy, OH with a KitchenAid Pasta Attachment, Model K5-A, KitchenAid, St. Joseph, MI, with a pasta die of 1.7 mm diameter holes).

Some noodles were dipped in gently boiling water for 10 seconds, then dipped in ice water before being dried.

The other method of noodle production was that developed by Lekalake (1993). It involved the formation of a dough ball by mixing 70 ml of distilled water to 100 g of flour. The dough ball was immersed in boiling water for 30 minutes, then cut into pieces and extruded. The extruded noodles were surface gelatinized in boiling water for 5 seconds, then dipped in ice water for 5 seconds.

Sorghum Noodle Drying Methods

The extruded noodles were separated and placed on plastic trays with baking paper liners. Noodles were dried a two step drying process in a proofing chamber (National Manufacturing Co., Lincoln, NE) at 60°C, 100%RH for 2 h followed by 2h at 60°C, 30% RH. Dried noodles were bagged in plastic bags before being stored at -18°C.

Non-sorghum, Commercial Noodles

Commercial Asian noodles were purchased in a specialty market in Texas. Sweet potato (Hanmi, Inc, Korea), broad bean (Tai Bean, Taiwan), egg noodle (Hong Kong Hang

Wah Trading Co, Hong Kong), tapioca starch (Cawai Trading Co., Hong Kong) and rice noodles (King Brand, Taiwan) were evaluated. Spaghetti from durum semolina (HEB, San Antonio, TX) was purchased in a local market.

Starch Stabilization

The viscosity was studied at critical stages in the noodle making process: flour, noodles after extrusion, noodles after drying and noodles after cooking. The samples taken after extrusion and after cooking were stabilized using the method outlined in Figure 3.

Analytical Methods

Moisture content of the noodles was measured using the AACC method 44-16 (AACC 1995).

Fracturability of dried noodles was measured with a texture analyzer (Stable Micro Systems Model TA-XT2. Texture Technologies Corp., Scarsdale, NY) interfaced with a Logical 386 computer. (Figure 4) The system included a color monitor and was controlled by software (SMS1-Stable Microsystems, version 1.05, Texture Technologies Corp., Scarsdale, NY). A 2.5-cm noodle was placed in a clamp with 0.5 cm of the noodle in the clamp. The clamp face was placed 6 mm from the aluminum guillotine probe (4x4 cm, 1 mm thick). TA settings were: mode = measure force in compression; options = return to start. Test parameters were: pretest speed = 10 mm/s; test speed 10 mm/s; post test speed = 10 mm/s; distance = 9mm, trigger force = 0.05N. The probe distance was set at 60 mm.

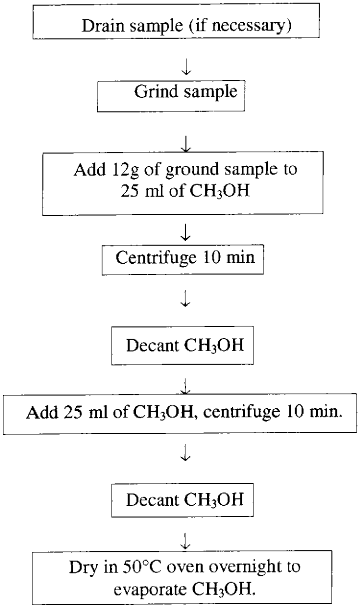


Figure 3 - Starch Stabilization with CH_3OH

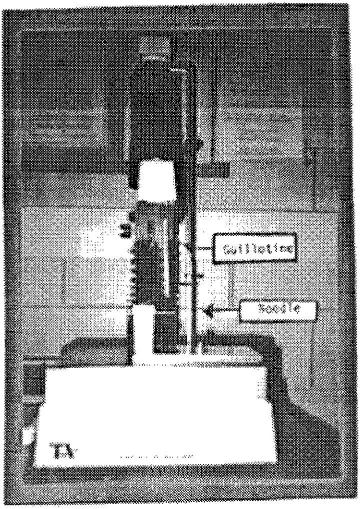


Figure 4 – TA-XT2 set up for noodle fracturability test

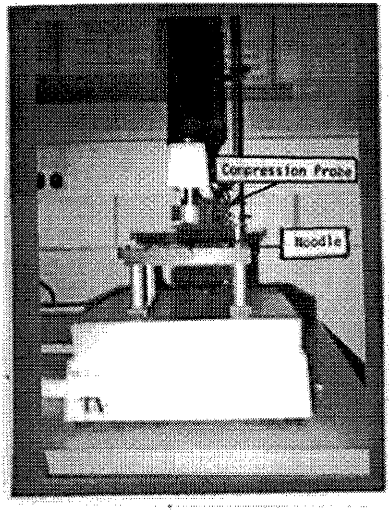


Figure 5 – TA-XT2 set up for noodle firmness test.

Firmness of cooked noodles was measured by AACC Method 16-50 for pasta (AACC 1995) with modifications. (Figure 5) A stainless steel cylindrical probe (5-cm diameter, 2-cm height) was used. The texture analyzer (Stable Micro Systems Model TA-XT2. Texture Technologies Corp., Scarsdale, NY) was used with the following TA settings: mode = measure force in compression; option = hold until time. Test parameters were set as follows: pre-test speed = 10 mm/s, test speed = 10 mm/s; and post test speed = 10 mm/s; time = 10 sec; trigger force = 0.1N. Probe distance was set at 60 mm.

Noodle Cooking Quality Tests

All cooking quality tests were done with distilled water.

Water uptake by noodles during cooking was measured by the method of Lekalake (1993) with modifications. Noodles (10g) were cooked to optimum cook time; rinsed and drained for 2 min before being weighed. After being weighed, the noodles were dried in a 105°C forced air oven overnight to evaporate off the water before being re-weighed. Water uptake (WU) was determined as follows:

$$WU = \frac{(\text{wet noodle cooked weight} - \text{cooked/oven dried noodle weight}) * 100}{\text{Cooked/oven dried noodle weight}}$$

Dry Matter losses were determined by AACC method 16-50 (AACC 1995) with modifications. Dry noodles (10g) were cooked in 300 ml of distilled water in a 400-ml beaker to their optimum cook time. Noodles were drained, rinsed and the water was retained. Weight of the beaker was recorded and the beaker was dried overnight in a hot air oven set at

105°C before being re-weighed. All cooking and waste water was evaporated. Dry matter loss (DML) was determined as follows:

Cooked, oven dried solids weight = weight of beaker + cooking solids – weight of beaker

$$\text{DML} = \frac{\text{Cooked, oven dried solids weight}}{\text{Noodle weight} - (\text{noodle weight} * \%\ \text{moisture})}$$

Pasting properties

Pasting properties of the flour and dried noodles were measured using the Rapid Visco Analyser (RVA) (Model No RVA-3C, Newport Scientific, Sydney, Australia). A slurry of 10, 14 or 16% solids was analyzed with the following time (min): temp (°C) profile: 2:50, 6.5:95, 10.5:95, 15:50, 18:50. A 160-rpm stirring rate was used.

Environmental Scanning Electron Microscopy (ESEM)

Selected dried, uncooked noodles were observed with an environmental scanning electron microscope (Electron Model E-3; Electroscan Corp., Wilmington, MD) at an accelerating voltage of 20 KV, a condenser setting of 46 and a working distance of approximately 8-mm. The samples did not require special preparation prior to viewing.

CHAPTER IV

COMMERCIAL NOODLE CHARACTERIZATION

Pasta, sweet potato, broad bean, egg, rice and tapioca noodles were evaluated. The noodles can be grouped into one of two categories: cereal based (pasta, egg, rice) and non-cereal based (broad bean, sweet potato and tapioca). Within the cereal-based noodles, both pasta and egg noodles are made from wheat.

Results

Moisture content, dry matter loss and water uptake was measured (Table I). The moisture content values range from 9.8 to 14.9. Water uptake during cooking is highest for rice noodle and lowest for spaghetti. The non-cereal, starch based noodles (tapioca, broad bean and sweet potato) have significantly lower dry matter loss than the cereal-based noodles.

The pasting properties of the cereal-based noodles were measured with the Rapid ViscoAnalyser (RVA) (Figure 6). Spaghetti and egg noodle (both made from wheat flour) reach the same peak viscosity at the same time, but the egg noodle exhibits less setback. Rice and experimental sorghum noodles have a lower peak viscosity, but the rice noodle setback is similar to the spaghetti setback. Sorghum noodle has the lowest peak viscosity and it reaches peak viscosity first.

The pasting properties of the non-cereal based noodles were also measured (Figure 7). The non-cereal based noodles were measured at lower percent solids. The tuber or root starch noodles (sweet potato and tapioca) swell less than broad bean. Tapioca noodles reached a low viscosity and had a relatively low setback.

Noodle Type	Moisture	Water Uptake	Dry Matter Loss
Egg	12.2 ± 1.1 %	338 ± 28%	8.4 ± 1.2%
Tapioca	14.9 ± 0.7 %	355 ± 50%	2.75 ± 1.2%
Broad Bean	11.6 ± 0.9 %	348 ± 23%	1.25 ± 0.6%
Rice	9.8 ± 1.5 %	433 ± 64%	8.8 ± 4.4%
Sweet Potato	13.3 ± 2.2 %	311 ± 24%	1.9 ± 0.5%
Spaghetti (pasta)	11.4 ± 0.22%	222 ± 21%	6.3 ± 0.5%

Table 1 - Properties of Commercial Noodles

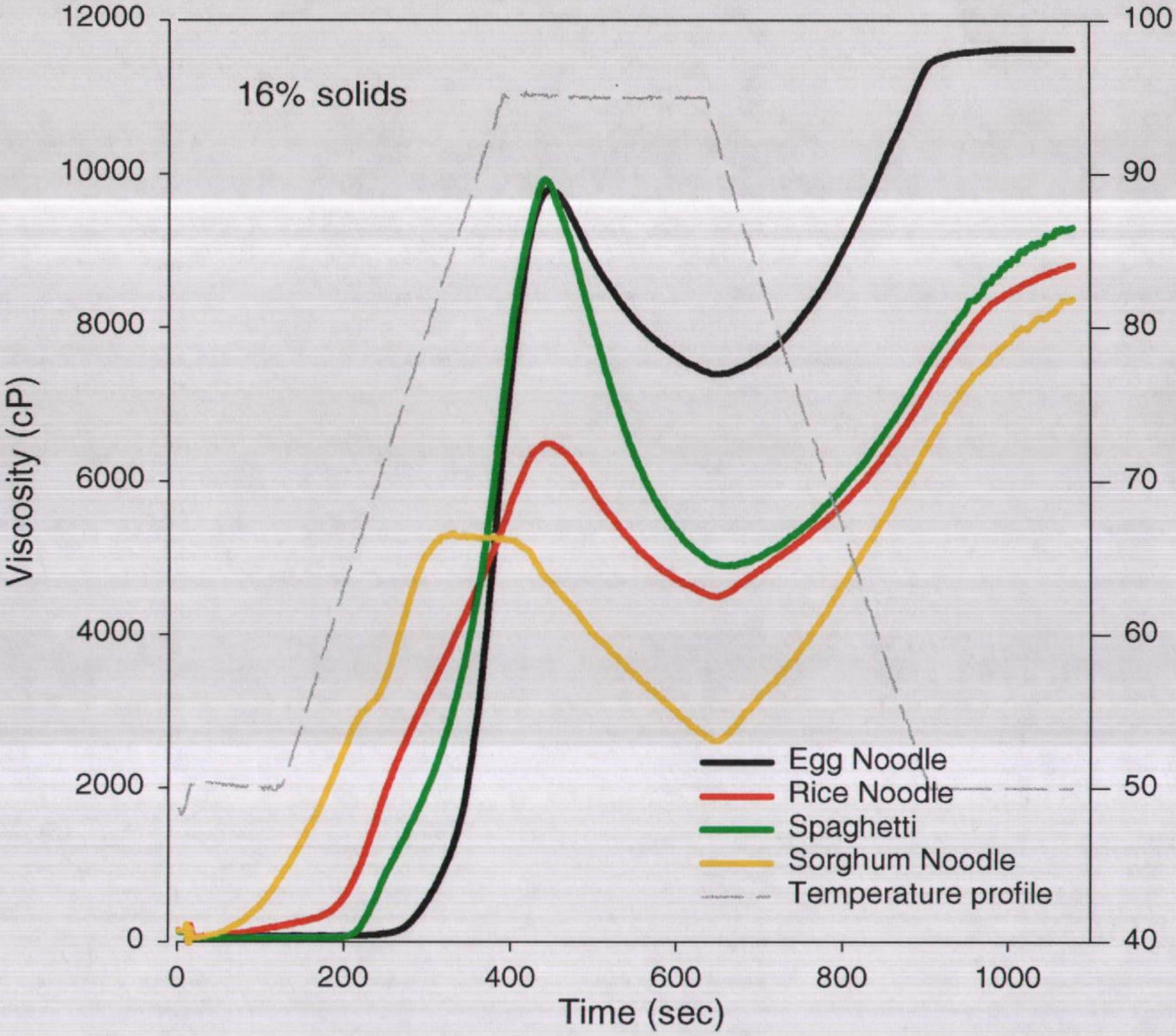


Figure 6 - Pasting Properties of Flour Noodles

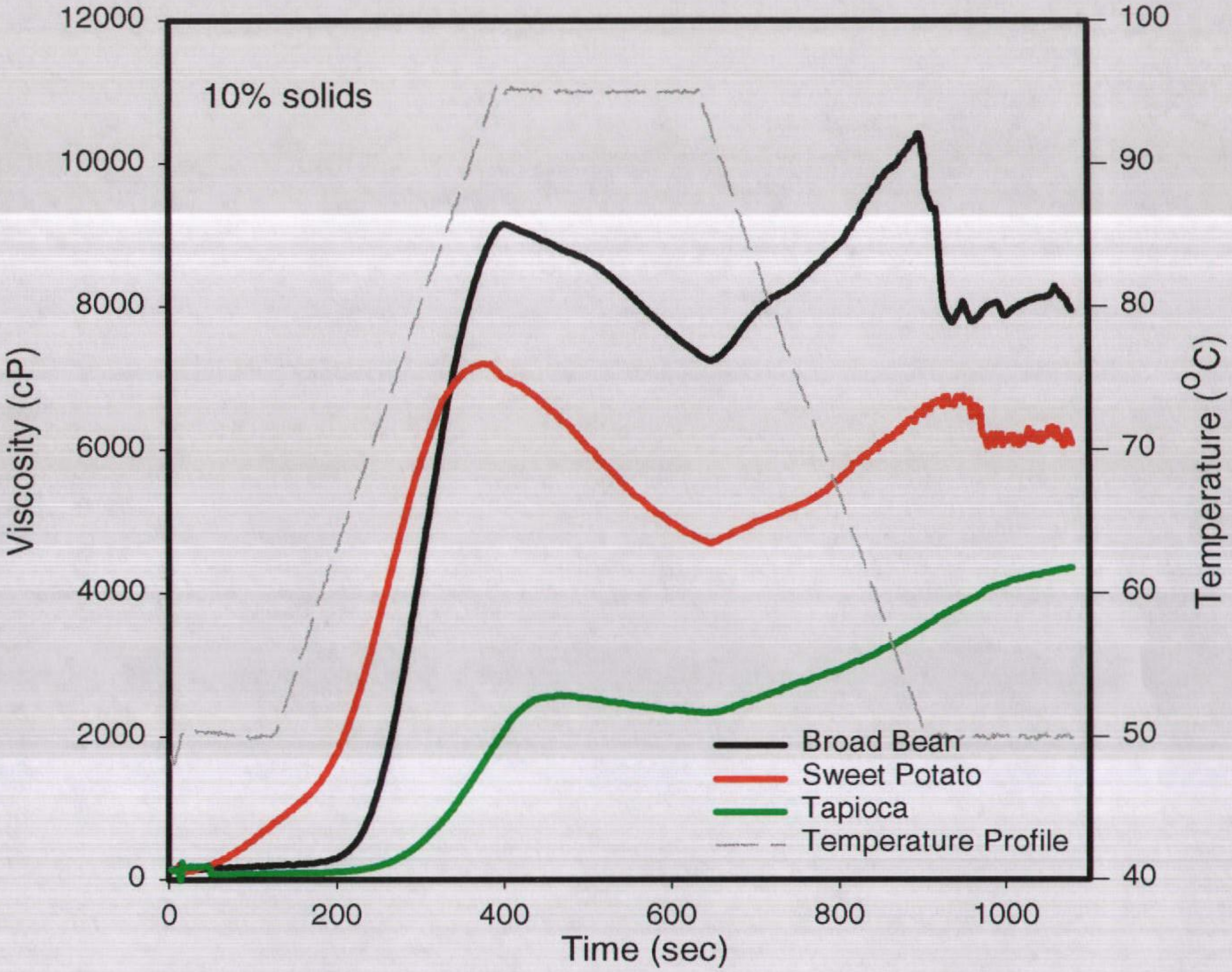


Figure 7 - Pasting Properties of Non-Cereal Starch Noodles

The fracturability of the dry noodle was measured using the TA-XT2 texture analyzer (Figure 8). Spaghetti and egg noodle break at the same distance (0.5 mm), but require different forces. Spaghetti required a much larger force to break than the egg noodle. The three non-cereal noodles were rubbery and did not break under compression. The non cereal noodles bent as the guillotine came down and sprang back when it was raised. The sweet potato noodle was the most rubbery, as it took the highest force to bend. Experimental sorghum noodles required the highest force to break.

The firmness of the cooked noodle was measured using the TA-XT2 texture analyzer (Figure 9). The sweet potato noodle was the firmest noodle requiring a higher force than any of the other noodles. Experimental sorghum noodle is the least firm, but it was similar to tapioca, spaghetti, and broad bean.

Dry noodle surfaces of the spaghetti and rice noodle and cross sections of the dry rice, egg and mung bean noodle were viewed using the Environmental Scanning Electron Microscope (Figure 10 and figure 11). The starch-based noodles have a thick, starchy continuous phase that is smooth and amorphous. Occasional starch granules are visible within the matrix. The protein based noodle (spaghetti and egg) is held together by a gluten matrix. Small endosperm pieces with intact starch granules are visible and suspended in the matrix. The bean starch noodle has a smoother surface than the two flour noodles.

Discussion

All of the non-cereal noodles rely on starch gelatinization for their structure, as does rice and sorghum noodles. The gelatinization and subsequent retrogradation creates a firm

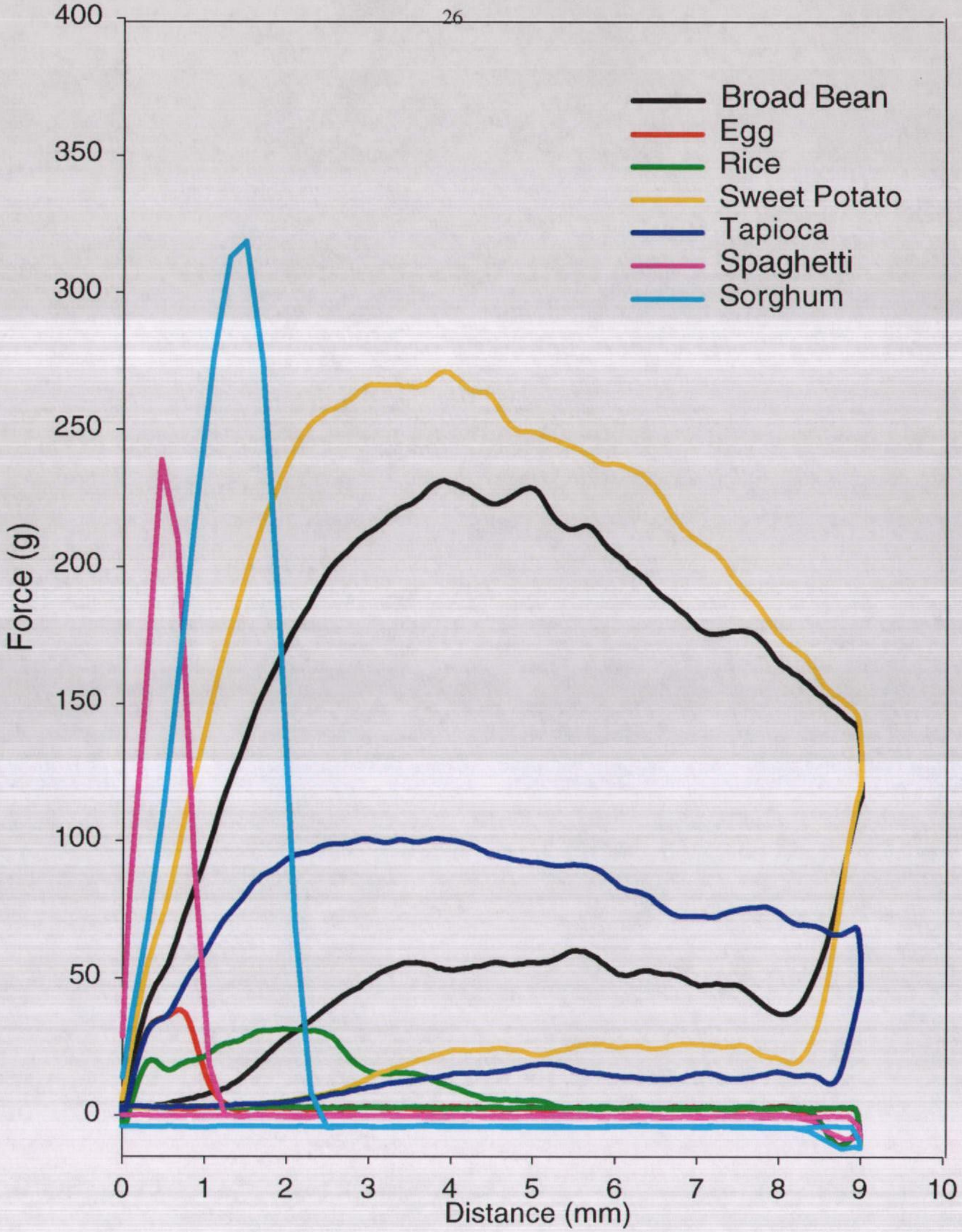


Figure 8 - Fracturability of Dry Noodles
as Measured by the TA-XT2 Texture Analyzer

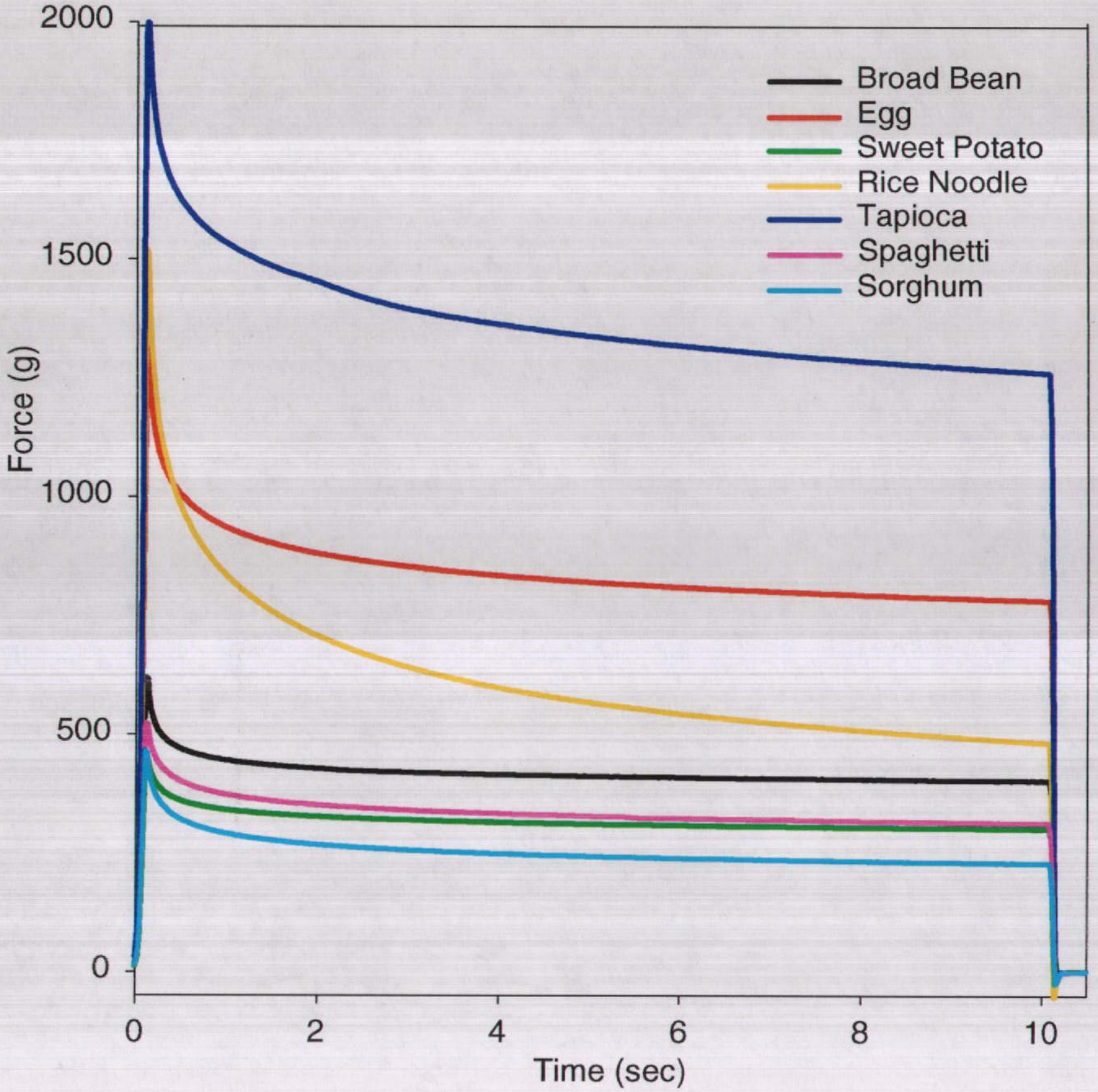
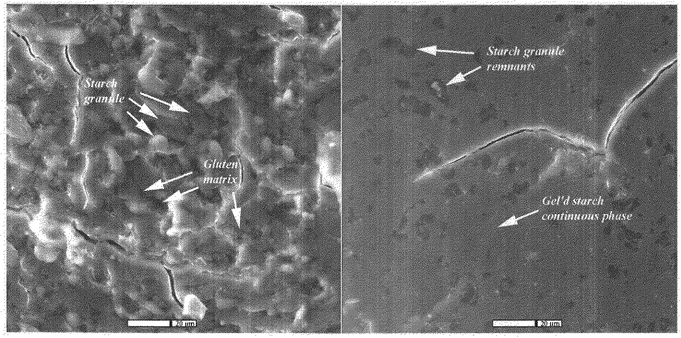


Figure 9 - Firmness of Cooked Noodles as Measured by the TA-XT2 Texture Analyzer



Protein based noodle- semolina

Starch based noodle- rice

Figure 10 – Cross Section of dry noodles using ESEM

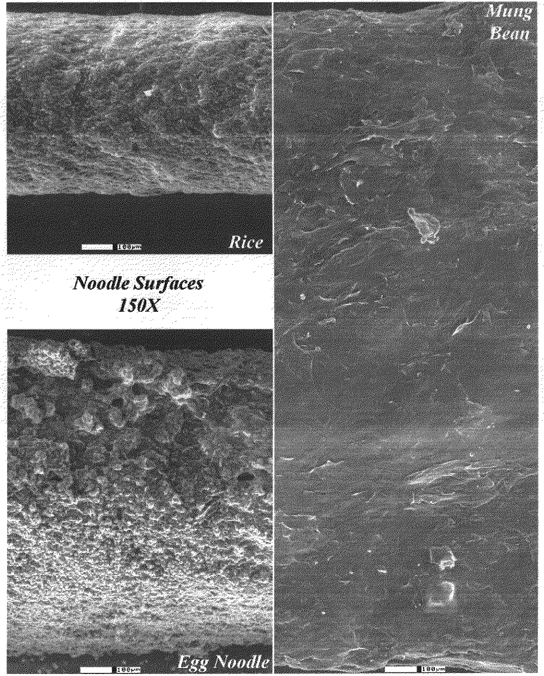


Figure 11 – Surface of dry noodles using the ESEM

starch network. The non-cereal noodles are made only of starch, while the rice and sorghum noodles are made from flour. Flour contains protein, ash and lipids, as well as starch.

The starch gelatinization in the non-cereal noodles creates a firm structure that is less penetrable by water, resulting in a lower dry matter loss. Retrograded starch is more resistant to water solubility (Bello et al 1995).

The RVA curves provide information on the starch characteristics in the noodles. The high peak on the RVA can be indicative of starch granules that are not encased and are therefore able to swell with RVA stirring (Hoseney 1994). The spaghetti and egg noodle reach the same peak viscosity, but the egg noodle has a lower set back. The protein from the egg gives the starch a firmer structure. The rice and sorghum noodles have a lower peak viscosity due to prior starch gelatinization during noodle processing. Less starch is in the native state.

The non-cereal, starch based noodles were measured at a lower percent solids because they exhibit the same swelling properties at lower solids. As stated earlier, these noodles are made primarily of starch, whereas the cereal noodles are made from flour. Legume starch pastes are more viscous than those of cereal starches, indicating that legume starches have a higher resistance to swelling and rupture than do cereal starches (Singh et al 1989). Kim et al (1996) found that potato starches show a much higher swelling power than bean starches. This may be due to the negatively charged phosphate ester groups within the potato starch granule. It has been shown that phosphorous content is highly correlated with peak viscosity, which results from high swelling power (Kim et al 1996). These noodles were extremely bendable, as evidenced by the fracturability test. Subjectively, the non-cereal starch noodles were very chewy when cooked and rubbery both dried and cooked. The flour based noodles all had a similar texture to common spaghetti.

As shown by the ESEM, structures characteristic of the native starch state are absent in the rice and broad bean noodles. This further supports the previous observations that the starch is completely gelatinized in non-wheat products (Mestres et al 1988). The commercial manufacturing of these products usually involves one or two heat treatments that lead to a complete gelatinization of starch. In pasta and egg noodle, the gluten completely surrounds the starch granules. The starch is not fully gelatinized, as evidenced by both the ESEM and the RVA pasting curves.

CHAPTER V

EFFECTS OF THERMAL PROCESSING ON SORGHUM STARCH IN NOODLES

The pasting characteristics of the sorghum starch at critical steps of noodle production were studied using the Rapid ViscoAnalyzer (RVA). The sorghum flour, the cooked dough after extrusion, the noodle after drying and the cooked noodle was analyzed. The cooked dough and the cooked noodle were both stabilized with methanol before being analyzed by the RVA.

Results

The pasting curve is shown in Figure 12. The highest peak is reached by the sorghum flour. The cooked noodle reaches a higher peak than the dried noodle and the extruded noodle. The dried noodle has a similar initial viscosity to the sorghum flour.

Discussion

The starch in the flour is almost completely native, as it has undergone little processing. This is evident in the low initial viscosity, high peak viscosity and the setback.

The peak viscosity reached by the cooked noodle indicates that there is still ungelatinized starch present after the cooking stage. This would indicate that there is more starch to be gelatinized in the processing to give a stronger structure to the noodle.

The starch in the dried noodle has retrograded, forming a strong structure that takes longer to penetrate by water. Retrogradation occurs as the noodle dries and is stored.

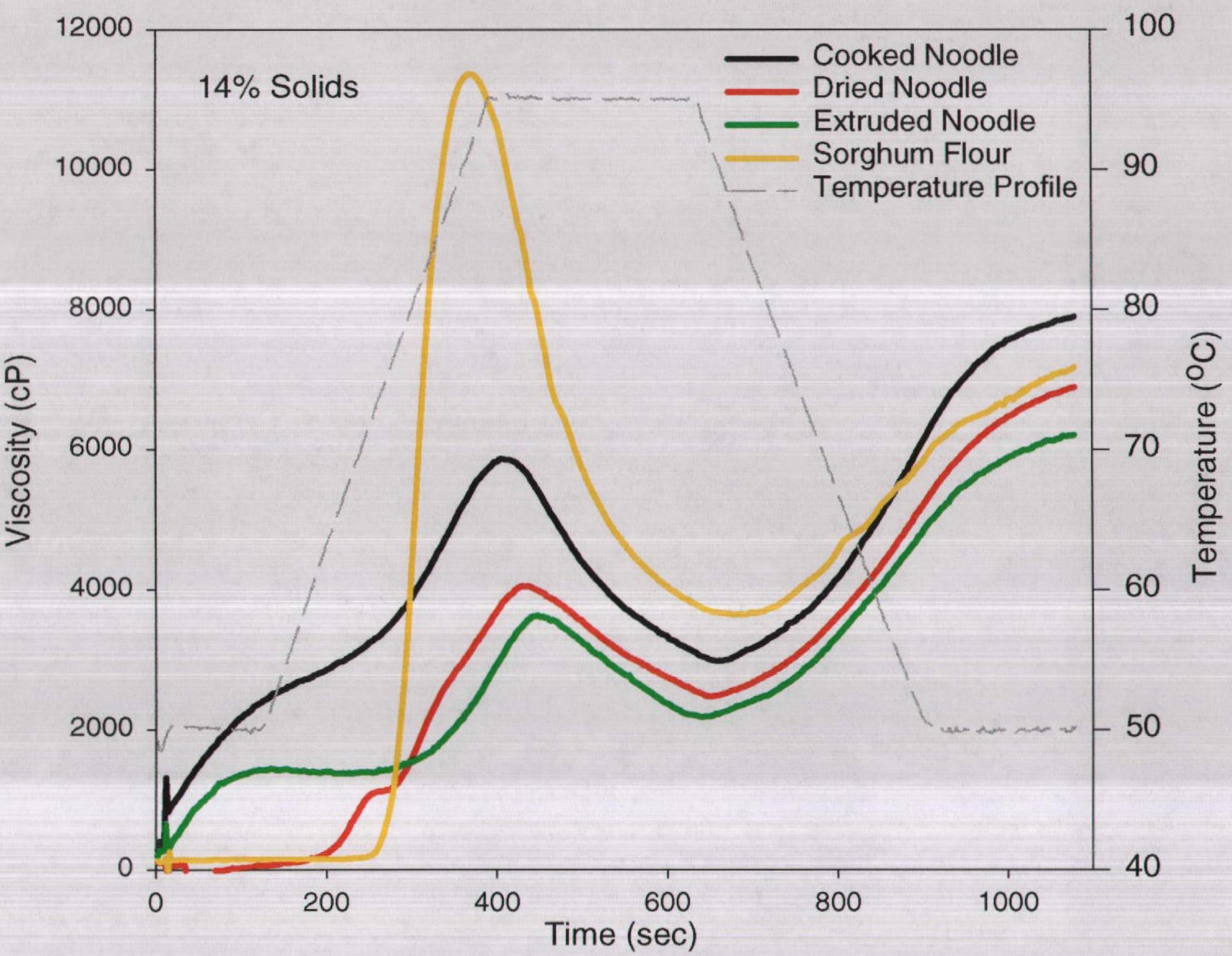


Figure 12 - Viscosity Changes During Critical Steps of Sorghum Noodle Production

CHAPTER VI

EFFECTS OF DRYING METHODS ON NOODLE QUALITIES

The effect of drying method on noodle characteristics and quality was evaluated. Four drying methods, all at 60°C, were investigated: 1) one stage – 100% RH for 4h; 2) two stage – 100% RH for 3h followed by 30%RH for 1h; 3) two stage – 100%RH for 3h followed by 30%RH for 2h; 4) two stage – 100%RH for 2h followed by 30%RH for 2h.

Results

Effects of drying methods on noodle properties are listed in Table 2. The moisture content of the finished dried noodles ranged from 9.1 to 11.0%. The highest moisture content was for the noodle dried at 100% RH for the longest time (4 hours). The lowest moisture content was for the noodle dried for the longest time (5 hours).

Dry Matter loss was high for all noodles. The dry matter loss was relatively similar for the noodles dried at 100%RH for at least 3 hours. It was lowest for the noodle dried for 2 hours in 100% RH.

Water uptake ranged from 218 to 232%. It was highest for the noodle that had a 2 hour 100% RH, 2 hour/ 30% RH. As with dry matter loss, the three noodles dried at 100% RH for at least 3 hours show similar results.

Pasting properties of the noodles was measured using the RVA (Figure 13). All noodles have similar pasting characteristics.

Drying Method (all dried at 60°C)	Moisture Content	Water Uptake	Dry Matter Loss
2 hr 100% RH, 2 hr 30% RH	9.5 ± 0.8%	232 ± 26%	27.4 ± 3.9%
3 hr 100% RH, 1 hr 30% RH	10.7 ± 1.7%	225 ± 20%	31.1 ± 3.8%
3 hr 100% RH, 2 hr 30% RH	9.1 ± 0.4%	218 ± 13%	32.3 ± 4.8%
4 hr 100% RH	11.0 ± 0.3%	218 ± 9 %	30.1 ± 2.0%

- All noodles were made from dough cooked for 75 seconds.

Table 2 - Properties of Noodles Dried at Different Times

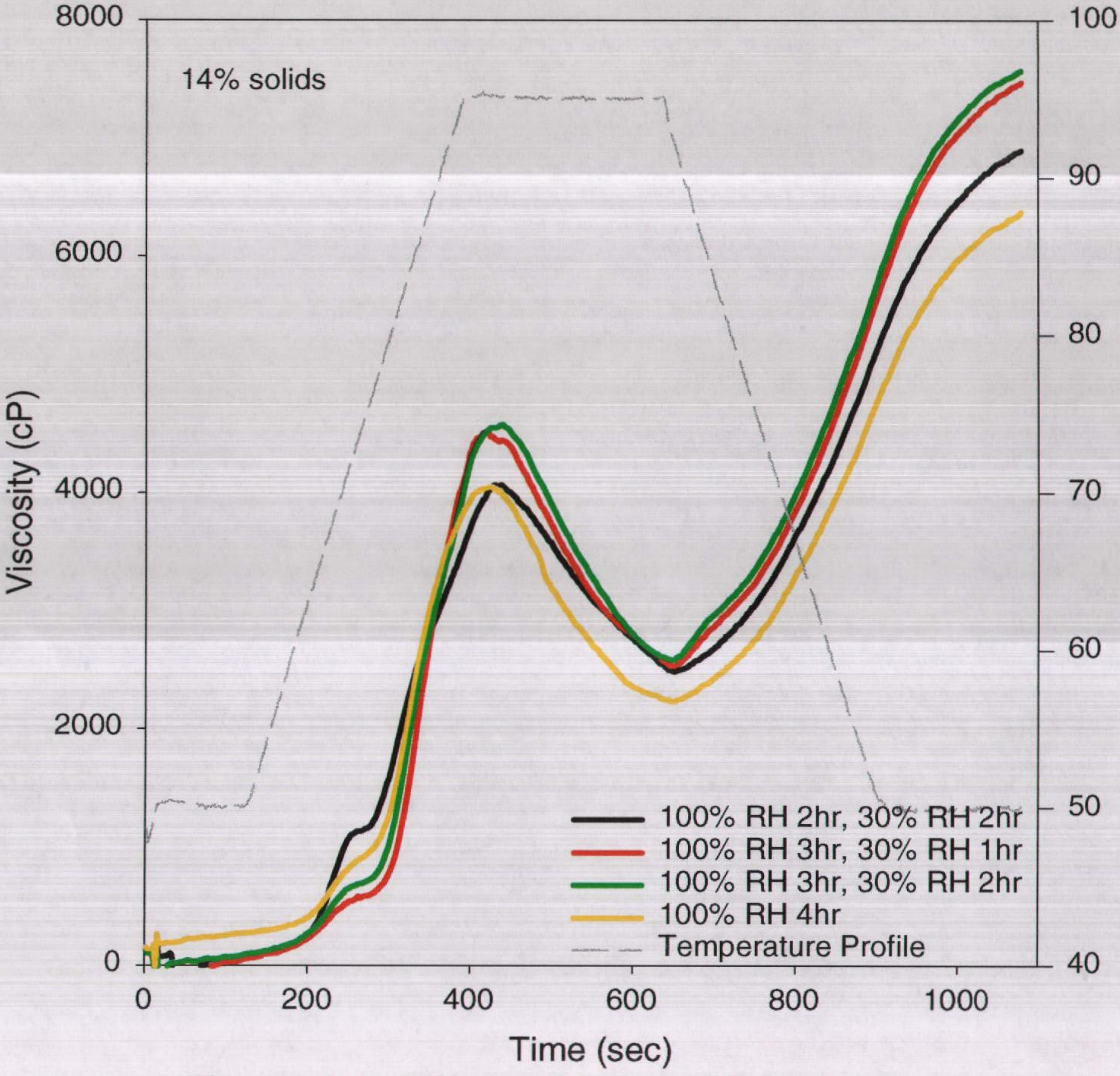


Figure 13 - Effect of Drying Conditions on Sorghum Noodle Pasting Properties

Discussion

In a two step drying method, the first drying stage provides moisture and heat for starch and protein movement, and the second drying stage provides heat to quickly set the structure (Kunetz 1997). The high relative humidity of the first stage also ensures moisture migration from the interior of the noodle strands to outside surfaces (Hou and Kruk 1999). The second stage, lower relative humidity, allows for a firming of the noodle surface.

Drying method had little effect on pasting properties of the noodle. This may indicate that there is little difference in starch modification among the different drying methods. The two noodles dried at 100% RH for 3 hours reach a similar peak, higher than the peak reached by the noodles dried at 100%RH for 2 hours. The extra hour at 100% RH may allow for greater starch gelatinization.

The dry matter loss is extremely high for all methods. The level of solid loss set by the Chinese National Standards is 10% (Lii and Chang 1981).

Overall, the drying methods studied do not seem to have a large effect on the noodle quality and characteristics.

CHAPTER VII

EFFECT OF DOUGH HEATING TIME ON NOODLE QUALITIES

The effect of dough heating time on noodle quality and characteristics was evaluated. One of the primary goals of this study was to lower the dry matter loss to a more acceptable percent. Because heating the dough may allow for further gelatinization of the starch, it was hypothesized that an increase in dough heating time would reduce dry matter loss.

The dough was heated in a microwave on high for 75, 105, 135 and 165 seconds. Each trial was removed from the microwave at 45 seconds and stirred, to promote maximum equality of heating. The dough was then extruded through the noodle maker and dried at 60°C by the two step method of 100% RH for 2h followed by 30% RH for 2 h.

Two trials involved the surface gelatinization of the noodle before drying. In this process, the noodle was dipped in boiling water for 10 seconds, followed by ice water for 10 seconds, then dried by the two step method. This step was used in the noodle making process of Lekalake (1993).

Results

The properties of the noodles made by different dough heating times are shown in table 3, figure 14 and figure 15.

The moisture content decreases as the cooking time increases for the non-surface gelatinized noodles. The noodles made from dough cooked for 165 seconds have very low moisture content in comparison to the other three cook times. Surface gelatinization decreased the moisture content for the noodles made from dough cooked for 105 seconds, as

Dough Heating Time	Surface Treatment	Moisture	Water Uptake	Dry Matter Loss
75 seconds	None	9.5 ± 0.8%	232 ± 26%	27.5 ± 3.9%
105 seconds	None	9.5 ± 0.1%	232 ± 31%	23.3 ± 0.2%
105 seconds	Surface Gelatinized	8.7 ± 0.1%	205 ± 19%	22.12 ± 2.9%
135 seconds	None	9.1 ± 0.6%	246 ± 30%	20.1 ± 2.4%
135 seconds	Surface Gelatinized	9.5 ± 0.3%	211 ± 12%	15.7 ± 0.5%
165 seconds	None	7.5 ± 0.2%	240 ± 12%	16.6 ± 0.2%

- All noodles dried at 60°C for 2 hr 100%RH, 2 hr 30% RH

Table 3 - Properties of Noodles Made by Different Dough Heating Times

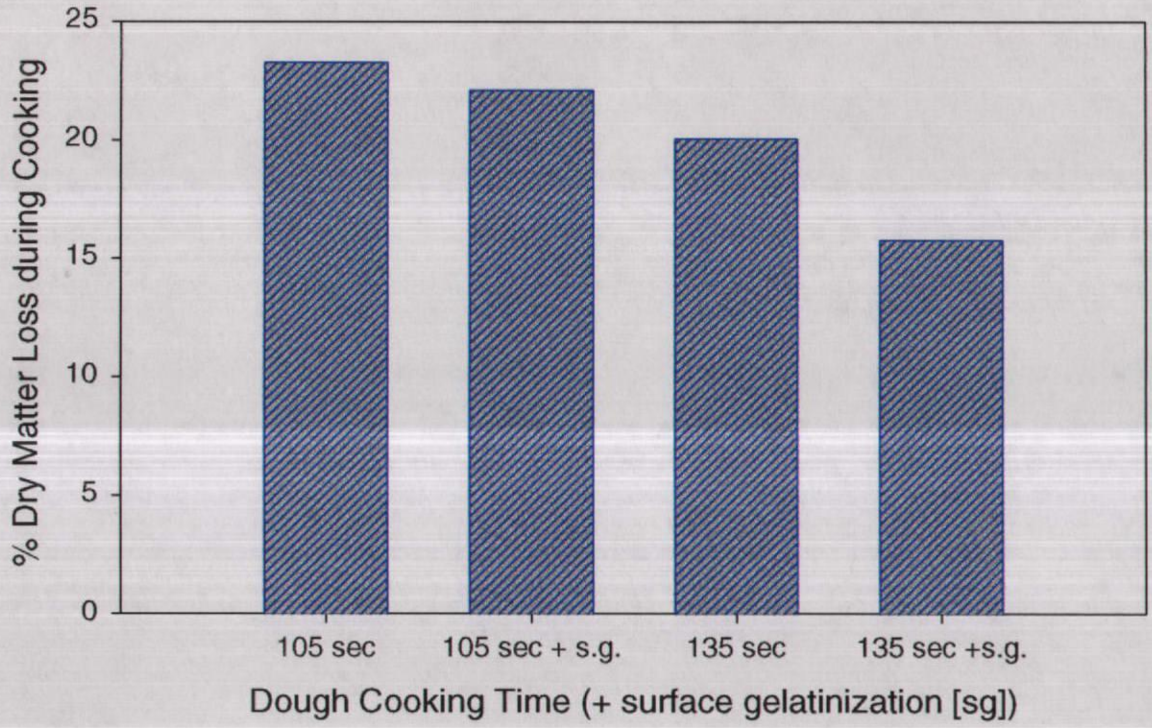


Figure 14 - Effect of Cooking Time and Surface Gelatinization on Dry Matter Loss during Cooking of Sorghum Flour Noodles

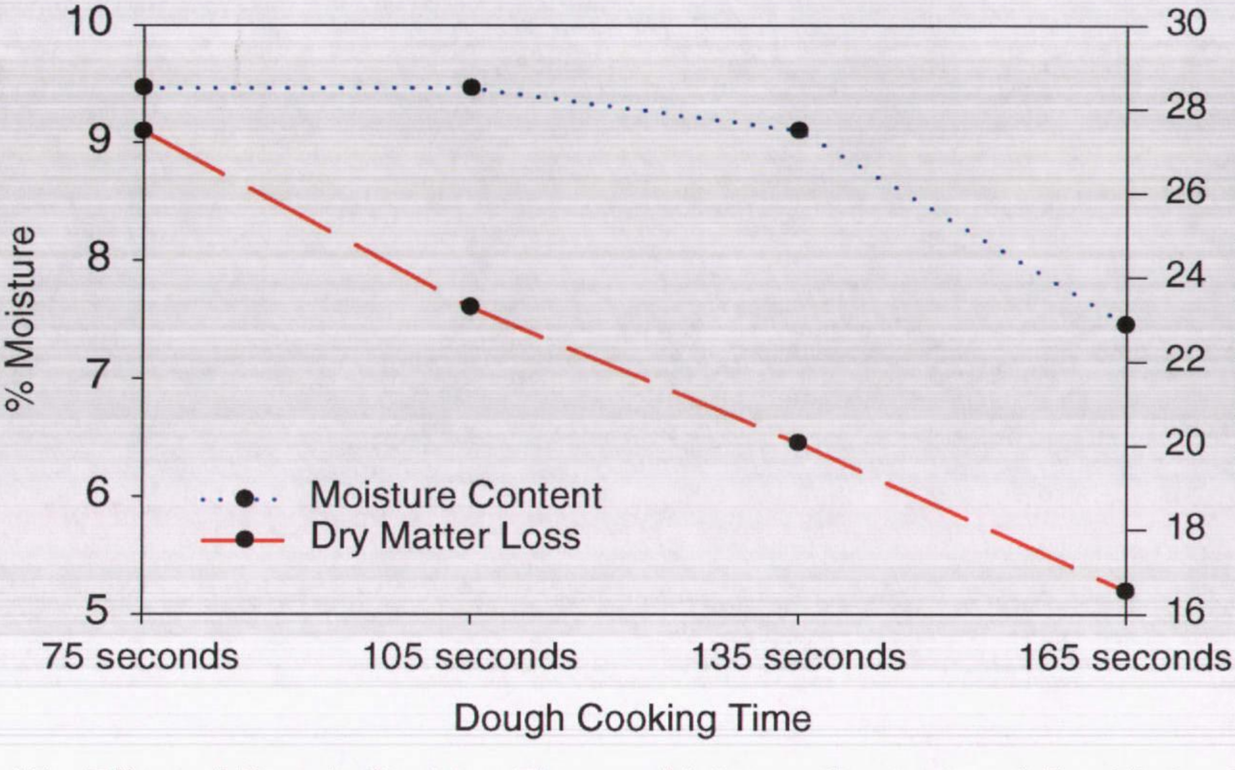


Figure 15 - Effect of Dough Cooking Time on Moisture Content and Dry Matter Loss of Cooked Sorghum Flour Noodles

compared to the noodles made from dough cooked for 105 seconds and not surface gelatinized. However, the moisture content increased slightly for the surface gelatinized noodles from dough cooked for 135 second compared to identical cook time noodles without surface gelatinization.

Water uptake increased slightly with cooking time for the non-surface gelatinized noodles. Surface gelatinization reduced the water uptake during cooking for both the 105-second dough cook time and the 135-second dough cook time noodles.

The dry matter loss decreased as cooking time increased (figure 15). The highest dry matter loss, 27.5%, was seen for the noodle with the lowest dough cook time, while the low dry matter loss was seen for the noodle with the longest dough cooking time. The decrease in dry matter loss appears to be linear over cooking time (figure 15). Surface gelatinization also decreases dry matter loss slightly(figure 14). There was a greater difference between the dry matter loss of the surface and non-surface gelatinized noodles made from dough cooked for 135 seconds, than that of the surface and non-surface gelatinized noodles made from dough cooked for 105 seconds. The noodle with the lowest dry matter loss, 15.7%, was the surface gelatinized noodle made from dough cooked for 135 seconds.

The pasting properties of the dry noodles were studied with the RVA (Figure 16). Overall, increase in dough heating time results in a lower peak viscosity of the dried noodle. The highest peak viscosity was reached by the noodle made from dough cooked for 105 seconds, followed closely by the noodle made from dough cooked for 75 seconds. The lowest peak viscosity was reached by the noodle made from dough cooked for the longest time, 165 seconds. All noodles displayed similar set back.

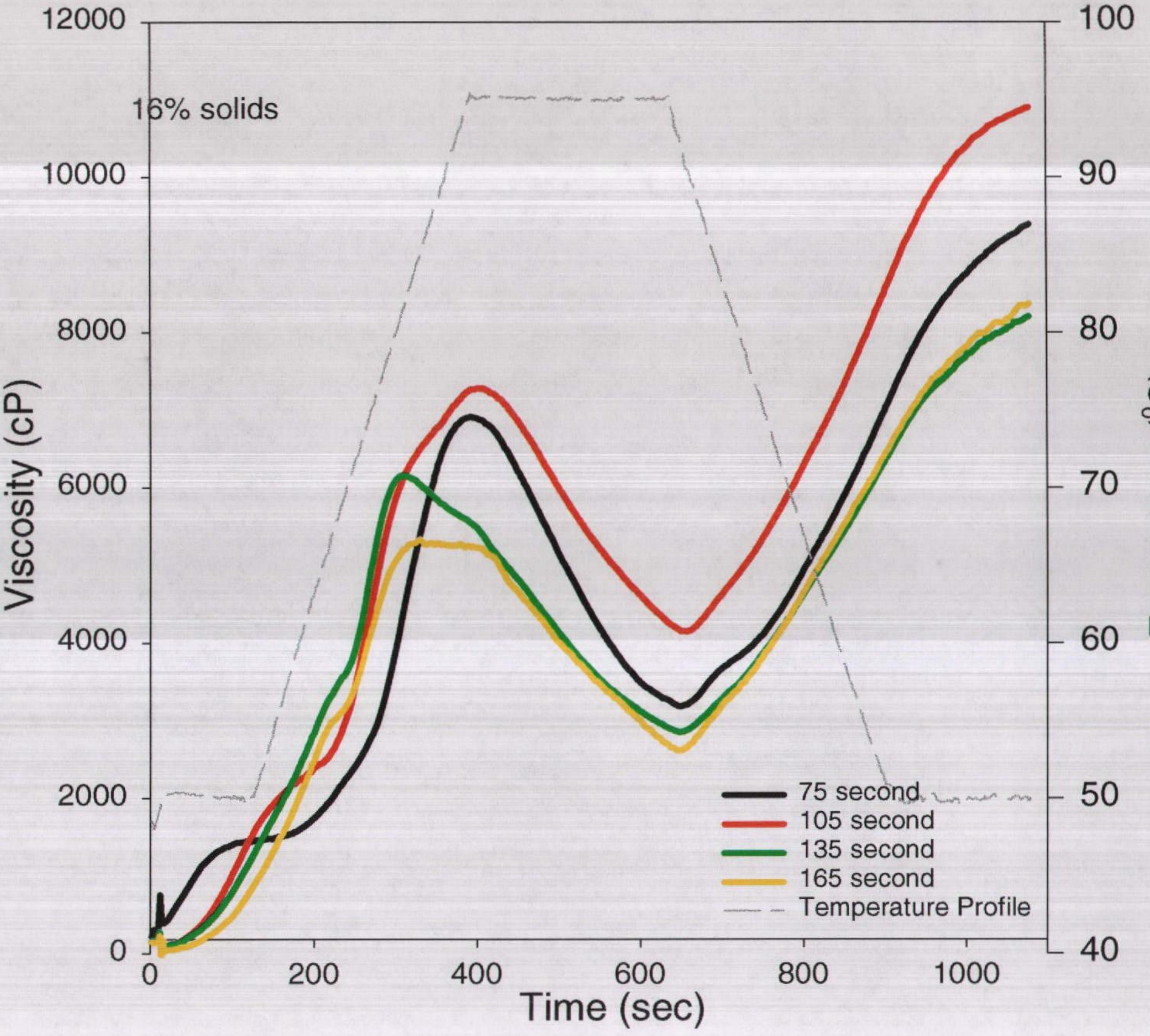


Figure 16 - Effect of Pre-extrusion Cooking Times on the Pasting Properties of Sorghum Noodles

The dry noodle fracturability was studied with the TA-XT2 texture analyzer (Figure 17). Increasing dough heating time increased the force required to break the noodle. The noodle made from the dough heated for 165 seconds required the most force to break. Surface gelatinization does not appear to have a great effect on noodle fracturability.

Discussion:

The cooking quality of gluten-free noodles depends on the gelatinization of the starch (Kim and Wiesenborn 1996). When the dough is heated, the starch gelatinizes as it takes up water and swells. The longer the heating time, the more the starch can gelatinize.

The decrease in moisture as the dough cooking time increases is probably due to the water evaporation as it cooks.

Surface gelatinization quickly 'sets' the starch on the noodle surface. A firm structure on the surface would make it less penetrable by water, as evidenced by the lower water uptake by the surface gelatinized noodles.

Dry matter loss is due in part to the starch at the surface of the noodle swelling and dispersing into the cooking water (Kim and Wiesenborn 1996). The more the starch is gelatinized, the lower the dry matter loss. Greater starch gelatinization provides a firm structure that is less dispersible when cooked.

Surface gelatinization reduces dry matter loss by further gelatinizing the starch on the surface of the noodle. This creates a barrier that water cannot penetrate as freely.

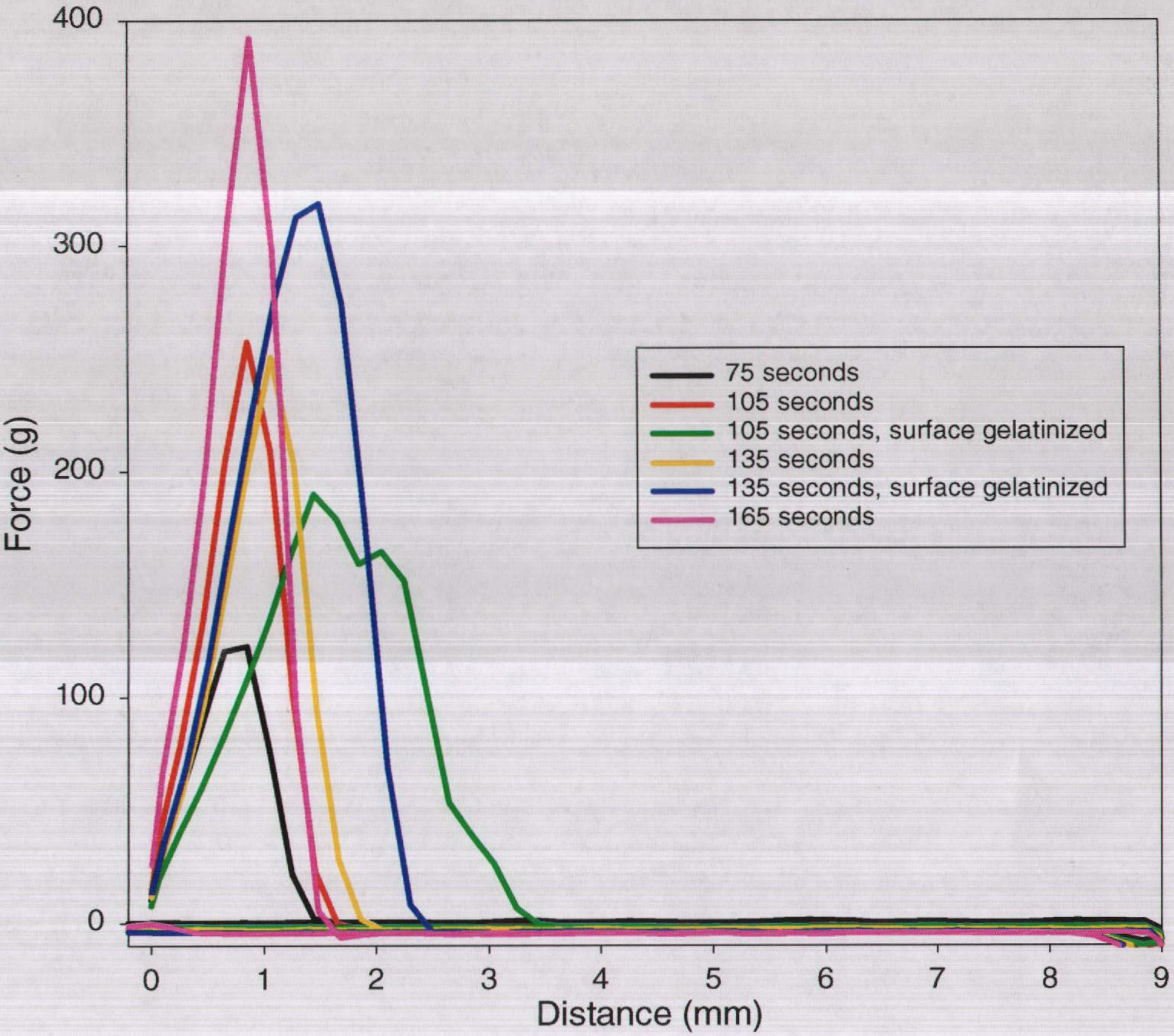


Figure 17 - Effect of Dough Cooking Time on Dried Noodle Fracturability

The RVA curve further supports the statement that longer heating time results in greater starch gelatinization. The peak viscosity gets lower as dough heating time increases. A low peak viscosity is indicative of highly modified starch.

Greater starch modification allows the noodle to retrograde more during cooking. This allows for a harder noodle. This is apparent in the fracturability test, where the strongest noodle was the noodle made from the dough with the highest cook time.

The noodle made from dough cooked for 165 seconds had the lowest dry matter loss of the non-surface gelatinized noodles. However, the dough was extremely tough and rubbery and as such, required a lot of force to extrude into noodles. This would be to labor intensive in an industrial setting. This property of excessive gelatinization causing extremely high extrusion pressures has also been seen in the production of rice noodles (Lekalake 1993).

The 'best' noodle produced in this trial, in terms of low dry matter loss, acceptable fracturability and water uptake, was the surface gelatinized noodle made from dough cooked for 135 seconds.

CHAPTER VIII

CONCLUSIONS

Different parameters affecting noodle quality was evaluated. Commercial noodles were studied and it was determined by microscopy and RVA curves that gluten free noodles must depend on starch gelatinization for their structure. The differences in starches used is related to the variation in cooking properties among the noodles. Non-cereal starch based noodles have a low dry matter loss due to extensive starch gelatinization. This is because the extensive starch gelatinization creates a strong, firm network of starch that is less dispersable in water.

Varying the drying methods had little effect on dry matter loss, water uptake and starch pasting characteristics.

Dough heating time has significant effect on dry matter loss, water uptake and starch pasting characteristics. The dough heating gelatinizes the starch granules; the more gelatinized the starch granule, the firmer the structure. The increased firmness of the dried noodles made by noodles with longer dough cooking time would also be an advantage if the noodle were to be packaged and shipped.

The best sorghum noodle was produced using the process of heating the sorghum flour with 47.3% flour to 95°C for 135 seconds in a microwave. The dough is extruded and surface gelatinized in boiling water before drying at 60°C under controlled conditions of 100% RH for 2 h followed by 30% RH for 2 h. The noodles produced by that method had the lowest dry matter loss and acceptable water uptake and fracturability.

Noodles with acceptable qualities can be made from sorghum. This would benefit areas where sorghum grows and wheat is unable to grow in that a native grain could be used. Using a domestic crop assists in feeding populations and it minimizes the importation of other grains. In the US where abundant wheat is grown, a sorghum noodle could be a product for people with gluten intolerance, celiac sprue. A sorghum noodle would be an alternative to a wheat-based noodle.

Further Research

Further research would include maximizing the water content in the dough formulation, studying addition of a protein source that could strengthen the noodle structure and studying air drying of the noodles. The RVA might be better utilized with a different time-temperature profile, namely the one studied by Whalen (1999).

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