NOODLE DOUGH RHEOLOGY AND QUALITY OF INSTANT FRIED NOODLES

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ABSTRACT

Instant noodles are becoming popular in North America due to some recognized factors such as ready-to-eat convenience, acceptable taste and preferred texture. These factors are created by the interactions of certain ingredients including water, starch, gum and others. This research aims to investigate the ingredients effect on dough rheology and its relationship with qualities of instant noodles.

Fundamental and dynamic tests were used to evaluate dough rheology. Relevant parameters include Young's modulus (E), energy at break (EB), storage modulus (G') and phase angle (δ). Increasing moisture content of noodle dough decreased its Young's modulus, energy at break and storage modulus. However, the phase angle of the noodle dough increased with increasing moisture content. Addition of gum increased in Young's modulus, energy at break and storage modulus of the noodle dough. Starch effect was less significant compared to gum and moisture. Moreover, interaction effects between water, gum and starch on some rheological parameters of noodle dough were also observed.

For noodle quality test, textural properties, rehydration rate and fat absorption of fried noodles were evaluated. Moisture content and the amount of starch added significantly influenced the maximum load before break point of the cooked instant noodles as determined by tensile test. Moisture content, gum content and starch addition also significantly affected the strain at break for cooked instant noodles. Starch alone and the interaction of gum and starch showed negative effects on fat absorption while all of moisture content, gum content and starch addition level showed positive effects on rehydration rate of instant noodles.

Most rheological parameters of noodle dough correlated with some textural and quality attributes of final instant noodles. There was a positive correlation between energy at break for noodle dough, the maximum load and the strain at break point for cooked instant noodles. Also, a positive correlation was found between the phase angle of noodle dough and strain at break for cooked instant noodles. However, a negative correlation was found between Young's modulus for noodle dough, maximum load and strain at break point for cooked instant noodles. This indicated that these rheological parameters of noodle dough have the possibility to predict the characteristics of the final instant noodles.

RÉSUMÉ

L'augmentation de la consommation de nouilles instantanées est principalement due à l'aisance du prêt-à-manger, à leur goût appréciable et à leur texture de choix. Ces facteurs sont issus de l'interaction des différents ingrédients des nouilles, dont entre autres, l'eau, l'amidon et les gommes. Ces ingrédients influencent les propriétés rhéologiques de la pâte à nouilles, et les caractéristiques de qualité des nouilles instantanées.

L'augmentation du taux d'humidité de la pâte à nouilles a diminué le module d'élasticité de Young (E), l'énergie de rupture (EB) et le module de conservation (G'). Cependant, l'angle de phase (δ) de la pâte à nouilles a augmenté avec une augmentation du taux d'humidité. L'ajout de gomme a augmenté le module de Young, l'énergie de rupture et le module de conservation de la pâte à nouilles. L'ajout d'amidon eut moins d'impact que l'ajout de gomme et le changement du taux d'humidité. De plus, les effets de l'interaction entre l'eau, la gomme et l'amidon sur de nombreux paramètres rhéologiques ont également été observés.

Le taux d'humidité et la quantité d'amidon ajoutée ont un effet significatif sur la charge maximale précédent le point de rupture des nouilles instantanées cuites tel que déterminé lors du test d'élasticité. Le taux d'humidité, la quantité de gomme et la teneur en amidon ont influencé de façon significative l'énergie de déformation de rupture pour les nouilles instantanées cuites. L'amidon seul, et l'interaction de la gomme et de l'amidon ont montré un effet négatif sur l'absorption des matières grasses, alors que l'augmentation de tous les taux d'humidité, toutes les concentrations de gomme et toutes les teneurs en amidon eut un effet positif sur le taux de réhydratation des nouilles instantanées.

La plupart des caractéristiques rhéologiques de la pâte à nouilles ont été mises en corrélation avec des caractéristiques de texture et de qualité des nouilles instantanées. Il existe une corrélation positive entre les caractéristiques de la pâte à nouilles (énergie au point de rupture et l'angle de phase) et les nouilles instantanées cuites (charge maximale et l'énergie de déformation au point de rupture). Cependant, une corrélation négative a été déterminée entre le module d'élasticité de Young pour la pâte à nouilles, la charge maximale, et l'énergie de déformation au point de rupture pour les nouilles instantanées cuites. Ainsi, ces caractéristiques rhéologiques peuvent aider à prédire les caractéristiques finales des nouilles instantanées.

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NOMENCLATURE

E	Young's modulus (MPa)
G'	Storage modulus (Pa)
G''	Loss modulus (Pa)
LM	Load at maximum (MPa)
γ	Correlation coefficients
SB	Strain at break (%)
δ	Phase angle (Degree)
X_1	Moisture content (%)
X_2	Gum content (%)
X_3	Starch addition level (%)

CONTRIBUTIONS OF AUTHORS

The current research contained several papers. Some of them will be submitted for publication in technical journals. Two authors were included in the research and contributions to the articles.

LI JUAN YU planned and conducted all experiments including the rheological test of noodle dough and quality test of instant noodles, analyzed data, put all results together, wrote papers under the supervision of Dr. MICHAEL NGADI. Dr Ngadi is the thesis supervisor and co-author who assisted in the planning and conduction of the research work including correcting, editing and reviewing the manuscripts.

CHAPTER 1: GENERAL INTRODUCTION

Instant noodles are mostly fried noodles which are made of flour, water, alkaline salt and other additives. The consumption of instant noodles is global due to their characteristics such as convenience to eat, easy to mass-produce, widely acceptable taste, preferred texture and affordable prices.

Texture is a critical characteristics of noodles and many ingredients such as starch, water and protein, and additives like gum play important roles in defining the textural properties. Water absorption level has a major impact on textural properties of oriental noodles (Hatcher 1999). Starch-related characteristics are widely recognized as the most important quality for Japanese white salted noodles (Batey 1997). Guar gum is a commonly used stabilizer in noodle making to provide viscosity, improve firmness, body and mouth feel in the final noodles. Through their ability to bind water, gums can reduce the oil absorption of fried instant noodles, and also increase the rehydration rate of instant noodles upon cooking or soaking (Hou 2001).

Rheological properties of dough can be used as quality indicators for the final cereal products. A variety of instruments, empirical, fundamental and dynamic rheometry had been used in the past few decades for rheological tests. Fundamental rheometry is capable of describing the physical properties of a material over a wide range of strains and strain rates. It allows direct comparison of results obtained by various testing instruments and researchers (Weipert 1990). Similarly, dynamic rheometers allow measurements without disturbing the inherent structure of materials. These instruments simultaneously measure the elastic as well the viscous components of dough and can give a better prediction to the quality of the final cereal products (Shiau and Yeh 2001).

Therefore, the rheological properties of noodle dough are useful for prediction of the quality characteristics of the fried instant noodles.

CHAPTER 2: LITERATURE REVIEW

2.1 GENERAL INTRODUCTION TO INSTANT NOODLES

Instant noodles are made up of dough consisting of flour, water, alkaline salt and other additives. They are mostly fried.

2.1.1 Evolution

Instant noodles originated from traditional oriental noodles which were first discovered in China. The history of noodles dates back at least to the Han Dynasty (206 BC-220 AD) in China. Their origin came from the hamlet of Shan Xi, which was located in a valley close to the source of the Yellow River. The noodles made there were called Yu noodles, and the manufacturing method was introduced into various districts along the Silk Road (Kubomura 1998).

In the Eastern Han Dynasty (25-220 AD), Chinese noodles were introduced to Korea and Japan by envoys, Zen priests or monks who were active in these regions. Gradually, noodles consumption spread from China to other Asian countries and beyond.

During the 13^{th} century, Marco Polo traveled to china and brought the Chinese noodle-making technology to Europe, where noodles were evolved into the current pasta products (Hou 2001).

Although pastas originated from oriental noodles, there are key differences between them. First, Pastas are usually made from durum semolina and water, while noodles are made from wheat flour, water and salt, ie common salt or alkaline salt. Secondly, noodles are characterized by thin strips slit from sheeted wheat dough, while pastas are extruded through a metal die under pressure. Thirdly, noodles are often consumed in water-rich condition, such as soup, while pastas are often eaten in dishes containing limited water (Hou 2001).

With a rapid economic development after World War II, most Japanese had less time to do cooking and needed a convenient food to feed the body. This prompted the Nissin Food Company Ltd. of Japan to finally develop the instant noodles in 1958 (Kubomura 1998). The instant noodles are precooked and this makes their cooking possible in just 3-5 min. in hot water or soups. By this convenience and economic reasons, instant noodles became popular in Japan.

Presently, instant noodles are consumed in more than 80 countries and have become internationally recognized foods. The world consumption of instant noodles was 43.4 billion packages in 2001 and most of the consumption took place in Asia. This included 16 billion in China, 8.6 billion in Indonesia, 5.3 billion in Japan and 3.9 billion in South Korea. However, North America also consumed 2.5 billion. It is expected that this consumption level will increase to 100 billion packages by 2010 (Pennapa 2001).

2.1.2 Classification of noodles

Presently, there is no standard classification for instant noodles in the world. But in some countries, such as Japan and Korea, local classifications do exist.

In Japan, based on the Japanese Agricultural Standard (JAS), instant noodles are classified into three types by their ingredients, namely instant Chinese noodles, instant Japanese noodles, and instant European-style noodles. Instant Chinese noodles are made from wheat flour, starch, egg powder, and "kansui" which is composed of alkaline salts. Instant Japanese noodles are made from wheat flour, starch, buckwheat flour, and egg powder, while instant European-style noodles are generally made from wheat flour or durum semolina (Kubomura 1998).

In Korea, instant noodles are classified into bag-type or cup-type based on the packaging method. Cup-type noodles usually have very thin noodle strands (proximately 0.8-1.0 mm) to facilitate the rehydration rate, which are readily served after pulling hot water into the cup and resting for 1-2 min. The noodle strands of bag-type are either square or round in shape and 1.0-1.2 mm or 1.4-1.6 mm in thickness, and are usually cooked in boiling water for about 3-4 min before serving (Kim 1996).

Based on the drying method, instant noodles can be classified into non-fried instant noodles and fried instant noodles. Non-fried instant noodles can be dried by hot blast air with low temperature (70-80°C). The advantages of air drying are that the products have a low fat content, and this makes many people to prefer them; and also, they have a longer shelf life because little fat rancidity is involved. However, the slow output of the process and lack of taste and texture make the products less popular in Asia compared to fried instant noodles. Fried instant noodles are popular due partly to the short processing time, short rehydration time and partly to its delicious taste and texture.

2.1.3 Ingredients, functions and nutritional considerations of instant noodles

2.1.3.1 Wheat starch

Wheat Flour is the major ingredient of instant noodles. Within the wheat flour, starch is the most abundant component, constituting about 70-75%, and it plays a considerable role in the end-product quality.

Starch occurs in nature in two primary structures namely amylose, the linear regular molecule, which comprises of ($\alpha 1 \rightarrow 4$)-linked glucose; and amylopectin, the highly branched molecule, which is based on a backbone of ($\alpha 1 \rightarrow 4$)-linked chains which are branched through ($\alpha 1 \rightarrow 6$)-links. Typically, amylose molecules range from 100,000 to 3,000,000 daltons, while amylopectin is considerably larger, ranging from 10,000,000 to 500,000,000 daltons. The ratio of amylose to amylopectin is a characteristic of the starch source (Shelton and Lee 2000).

Starch naturally exists in a granular state. The granules vary in size and shape, depending upon species, and can range from approximately 1 μ to as large as 120 μ. Most granules are 20-30 μ.

Panozzo (1993) found that peak paste viscosity of wheat starch measured using the Newport Rapid Viscoanalyzer (RVA) was highly correlated with sensory eating quality of Japanese and Korean-style salted noodles. Oda et al. (1980) found that the starch pasting properties also had an important effect on the eating quality of Japanese noodles. Toyokawa et al. (1989) used fractionation and reconstitution studies to find that there was an optimum amylose/amylopectin ratio for good Japanese noodle quality. Thus the measurement of starch peak paste viscosity has become a widely accepted means of selecting for improved quality for Japanese noodles. Nagao et al. (1977) reported that selected Australian wheats and American soft white and white club wheats showed favorable characteristics when used to produce Japanese-type-noodles. They also reported that the starch in those flours were found to swell at a relatively low temperature in the amylograph compared to other flours which provided evidence that high-swelling starch in wheat flour is beneficial to the quality of Japanese salt noodles.

2.1.3.2 Wheat protein

Wheat flour contains between 8 and 16% protein. The protein component of wheat flour is represented by albumin, globulin, gliadin and glutenin. Each of these has different chemical and physical properties. In the preparation of the dough, albumin and globulin, although necessary, have relatively marginal functions, while gliadin and glutenin are the two protein fractions insoluble in water, which form gluten (Huang and Morrion 1988).

The influence of flour protein on the quality characteristics of dry noodles was investigated by Oh et al. (1985a) who found that the optimum cooking time of dried salt-noodles increased linearly with flour protein content. However, flour protein content was not correlated with surface firmness. Surface firmness may vary with the degree of gluten development in the dried salt noodle (Oh et al. 1985b). Dexter et al. (1983) reported that surface stickiness of spaghetti was partly related to the semolina protein content. However, the differences in flour protein level does not always account for the differences in noodle quality.

When hard wheat and soft wheat dried salt noodles with similar protein content were compared, the hard wheat noodles were generally darker and stronger but less firm at the surface (Oh et al. 1985a). These differences may be due to protein quality or other factors, rather than the protein level. Also, the cooking time of hard wheat noodles increased linearly with protein content while the thickness of noodles also varied with protein content, but not linearly. However, the internal firmness of cooked, hard wheat noodles increased linearly with increased protein content. The same correlation is well known for cooked pasta (Oh et al. 1985a).

The gluten fraction of flour affected the raw and cooked Japanese noodle color but did not affect the cooked noodle texture (viscoelasticity). The presence or absence of the water-soluble fraction did not affect the cooked noodle texture or other measured properties (Toyokawa et al. 1989).

Protein quality and quantity by Sodium Dodecyl Sulfate (SDS)-sedimentation test are positively correlated to the eating quality, such as firmness and elasticity of Chinese white and yellow noodles. Researchers found that γ -gliadin bands 44.5 and 45.0 separated by acid electrophoresis was associated with strong gluten and good noodle eating quality, and band 41.0 was associated with weak gluten and poor noodle eating quality (Huang and Morrion 1988).

2.1.3.3 Water

Water is essential in noodle making. When water is added to the noodle flour and mixed, the gluten network is formed, which contribute to the structure of noodles. Addition of water contributes to the viscoelastic properties of the dough and increase the smoothness of the noodle surface (Hou 2001). If higher amount of water are added, a very soft, uniform and smooth dough forms quickly. But with less than 35% water in instant noodle formula, the dough can not fully develop its gluten network.

The optimum water absorption for instant noodles should hydrate the surface of flour particles to form cohesive noodle granule during mixing and to develop the gluten during sheeting. The amount of added water depends principally on flour protein content, particle size, starch damage, and pentosans (Oh et al. 1985).

Oh et al. (1985) varied water absorption from 30 to 38% in the production of long, dry noodles. Absorption was shown to affect noodle color, wet strength, and dry strength. Furthermore, when absorption was varied more than 2 or 3% from optimum, sheeting, cutting, and drying of noodles became difficult. The optimum absorption of noodle dough increased with starch damage and fineness of granulation of flour (Pomeranz 1988).

2.1.3.4 Starch additives

Native or modified potato starch, tapioca starch or other equivalents are often added in high quality instant noodles. These starches have typically high viscosity, rapid swelling characteristics, and low gelatinization temperature. As a result, they can improve the steaming and cooking quality of noodles, providing a more springy texture and quicker rehydration time. Modified starches have improved gelling properties and freeze-thaw stability. So they are especially beneficial to long life noodles that require thermal processing or freezing. Further more; starches can give a whiter or lighter background color to the finished noodles (Hou 2001). Therefore, except the wheat starch which already exists in the flour, other starches can be added to give high quality to instant noodles.

2.1.3.5 Gum additives

Like starches, gums provide viscosity and texture, and can be used by themselves or in combination with starch to create certain effects. In general, most consumers prefer the texture of instant noodles to be firm and have a good chewy bite to it. But some noodles, despite their initial firm texture, become soggy in the midst of the eating period. So currently, there is a need for manufacturers to come up with a product that can withstand a longer heat treatment.

Another problem is oil absorption in instant noodles during the frying stage. Less oil absorption not only reduces production cost, but also allows the manufacturer to have a healthier, less greasy product with a longer shelf life.

Guar gum, locust bean gum, alginates and carboxymethyl cellulose (CMC) are common stabilizers used in noodle making to provide viscosity, improve firmness, body and mouth feel to the final noodles. Through their ability to bind water, gums can reduce the oil absorption of fried instant noodles, and also increase the rehydration rate of instant noodles upon cooking or soaking (Hou 2001).

Guar gum is the commonly used stabilizer in instant noodles. It is a galactomannan polymer extracted from the seed of Cyamopsis tetragonolobus which has been cultivated for centuries by the farmers in semi-desert regions of northwest India. It has an approximate 1: 2 ratio of D-galactose to D-mannose (Fox 1997). Galactose side chains occur on the mannose backbone at every third mannose unit, on average. This relatively high degree of substitution increases solubility characteristics, making guar gum soluble in cold water. Guar gum solutions display stable viscosity over a pH range of 4 to 10. Viscosity and hydration rate of guar gum vary depending on the processing method used in the preparation of the gum (Edward 1995).

2.1.3.6 Nutritional considerations

From the point of view of ingredients in instant noodles, the first item is wheat flour. In dietary terms, wheat flour is a complex carbohydrate, a molecule that contains carbon, hydrogen and oxygen. It is required for the processing of nutrients within the body and it is also our main source of energy. Without carbohydrates, the body begins to search for other sources of nourishment, usually from stored fat and body protein, which are essential for our body (Nantel 1997).

The second largest nutrient group in instant noodles is fat. Most instant noodles are dried by deep frying, and only 3-4% are air dried. Fat is a dietary requirement. Nutritionists recommend that about 20 to 30% of daily calories requirement come from fat. But not all fats are equal. In Asia, most manufacturers use palm oil, a pleasant-tasting fat and is highly saturated (Rossel 2001), which gives risk to coronary artery disease. Although now in North America, frying oil is typically composed of mixtures of canola, cottonseed and palm oils, there is still health concern for the high level of oil absorption in fried instant noodles by consumers. But health concerns aside, most noodle lovers would choose a fried variety simply because oil makes foods taste better. So there is a need to find a balance between nutrition and mouth-feel.

Gums are a source of soluble dietary fiber, and as such are metabolized in the large intestine and do not contribute as a nutrient source (Ward and Andon 1993). Gums are common stabilizers used in noodle making to impart viscosity to the noodles when cooking in water, providing improved firmness, body and mouth-feel. These compounds normally have a high molecular weight and so are used at low levels (0.1-0.5%). Through their ability to bind water, stabilizers can reduce the oil absorption of fried instant noodles, and also increase the rehydration rate of instant noodles upon cooking or soaking (Hou 2001).

2.1.4 Processing aspects of instant noodles

The major processing steps for instant noodles are described as follows:

The first step is mixing, the purpose of mixing is to blend water, flour and other ingredients together to form the noodle dough; the second step is sheeting, which develops the noodle dough into a uniform and smooth noodle sheet; next comes slitting and waving, in this step, the noodle sheets are cut into uniform strands and waved into the desired shape and size; then comes steaming, the purpose of steaming is to cook the noodles, provide a gelatinized state to starch and give a viscoelastic texture to final product. After steaming, the product is dried. Drying must be fast in order to keep the starch in the gelatinized state. It is the gelatinized state of starch that makes the noodle "instant". So this is the major difference between normal noodles and instant noodles. Finally the product is cooled and packaged to maintain its quality.

2.1.5 Quality evaluation of instant noodles

Generally, there are four principal quality factors which determine food quality. These are appearance (color, shape, size), flavor (taste and odor), texture and nutrition. Other factors, such as cost, convenience, and packaging, are also important but are not considered quality factors of foods. Nutrition, on the other hand, is a quality factor that is not perceived by the senses (Bourne 1995).

The sensory acceptability factors of foods are extremely important because people obtain great enjoyment from eating their food and, furthermore, the enjoyment of food is a sensory pleasure that is appreciated during the whole life.

As earlier mentioned, instant noodles are popular today, and this is partly due to their texture which appears to be peculiar. It is well known that instant noodles really have a specific texture. Kubomura (1998) expressed the texture of instant noodles as rubbery, firm, or smooth and described poor noodle texture as rough or sandy. And up till now, this expression has not been given any further scientific description.

A major challenge facing food developers is how to accurately and objectively measure texture and mouth-feel. Texture is related to a number of physical properties (e.g., viscosity and elasticity), and the relationship is complex. Describing texture or mouth-feel in a single value obtained from an instrument is impossible. Mouth-feel is difficult to define. It involves a food's entire physical and chemical interaction in the mouth - from initial perception on the palate, to the first bite, through mastication and finally, the act of swallowing (Marsilli 1993).

Based on the efforts of some research pioneers, two general methods can be used for direct textural evaluation of instant noodles, namely sensory and instrumental. Some researchers also mentioned chemical method as a tool for indirect textural evaluation (Dexter 1985; D'Egidio et al. 1993).

Sensory evaluation of noodle eating quality is a direct and ultimate method for evaluating the final product. Nevertheless, sensory evaluation is very subjective, laborious and expensive and, therefore, quicker and more accurate methods to identify wheat flour suitable for noodles are required (Hou 2001).

Instrumental measurement of cooked noodle texture can be a reliable and convenient alternative evaluation to the sensory method (Oh et al. 1983; Lee et al. 1987; Hou et al. 1997). Due to the above reasons, instrumental method is widely used for the measurement of noodle texture (Oh et al. 1983; Baik 1994; Hatcher et al. 1999 and Epsteint et al. 2002).

In addition to instrumental test, several chemical techniques have been developed to relate certain parameters to the final noodle texture (Dexter et al. 1985; Sgrulletta et al. 1988; Matsuo et al. 1992; D'Egidio et al. 1993; Edwards 1994).

2.1.6 Noodle quality and dough rheometry

Rheological properties of dough are widely used as quality indicators of the final product, particularly in wheat development programs. A variety of instruments, empirical, fundamental and dynamic rheometry has been used for assessing rheological characteristics of bread, pasta and noodle dough during the past decades (Irvine et al. 1961; Dexter & Matsuo 1980; Cubadda 1988; Oliver and co-workers 1995; Shiau and Yeh 2001).

Rheometry is a necessary and powerful technique for explaining and predicting the quality of cereal based foods (Weipert 1990). Most of the important knowledge in dough rheology has been obtained by the use of the basic rheometry (Muller 1975).

Empirical rheometry, like the mixograph or farinograph, employs a rather high deformation force to develop and subsequently destroy dough structure. Similar force levels are used to stretch the dough in an extensigraph or alveograph. Normally, the force needed to destroy the structure is considered to be the dough's strength and is correlated with the flour's baking behavior (Weipert 1990). Because only one deformation force is used, the result is a single-point measurement. For this reason, these mechanical instruments only describe mechanical properties of dough and not the detailed physical properties (Szczesniak 1988).

Fundamental rheometry is capable of describing the physical properties of a material over a wide range of strains and strain rates. It produces not only a single-point viscosity value, but also a curve (stress vs. strain or stain rate) expressing the flow properties of the measured sample, and exact measurement of the stress and strain rate. The results are obtained in absolute physical units (e.g., Pa/sec, and Pa.sec). Similarly, basic rheometry allows direct comparison of results obtained by various testing instruments and researchers (Weipert 1990).

The advantage of dynamic rheometry is not only in the absolute values obtained but also in the possibility of utilizing various strains (or deformation forces) to obtain a more complete view of a material's physical properties. Very low strains, which allow measurements but do not disturb or destroy the inherent structure are important in describing the time and temperature dependent changes in materials. The usefulness of fundamental rheometry has increased due to the introduction of the dynamic oscillatory rheometers. These instruments simultaneously measure the elastic as well the viscous components of dough and several researchers found that rheometry can give a better prediction to the quality of final products (Oliver, wheeler and Thacker 1995; Weipert 1990; Shiau and Yeh 2001).

2.2 EVALUATION OF THE TEXTURAL PROPERTIES OF INSTANT NOODLES

Texture characteristics are one of the important factors in quality aspect of instant noodles. Technological progress has helped improve the quality of instant noodles, particular their texture (Kubomura 1998).

2.2.1 Commonly used texture evaluation methods

Overall, there are two methods to evaluate food texture, namely sensory and instrumental methods. The sensory method of developing a texture profile utilizes a human taste panel and provides the ultimate test which can not be completely duplicated by any instrumental procedure. Instrumental methods, however, are much less costly and time consuming than sensory tests. Moreover, they are often correlated to the critical sensory attributes which allow some measure of consumer acceptability.

Generally, the principle for conducting texture test is similar to rheological test; some times, they are even hard to distinguish. Hence most of the rheological instruments and methods can also be used for texture test. These include compression test, tensile test and shear test. Below are the three commonly used methods in noodle test.

2.2.1.1 Compression test

Compression test is designed to mimic human eating actions (chewing and biting). During the test, a sample is placed in the test area of a texture analyzer, and a force is applied using a probe, knife, or fixture. The resulting sample deformation data are analyzed. The results include information on firmness, hardness, and fractuability.

2.2.1.2 Texture profile analysis (TPA):

TPA method is widely used for texture evaluation because the compression method only performs one bite. However, the human eating action normally consists of several bites. In order to better describe the eating actions of humans, the TPA method was presented by Peleg (1976). The TPA test performs two bites; every bite includes compression and decompression cycles.

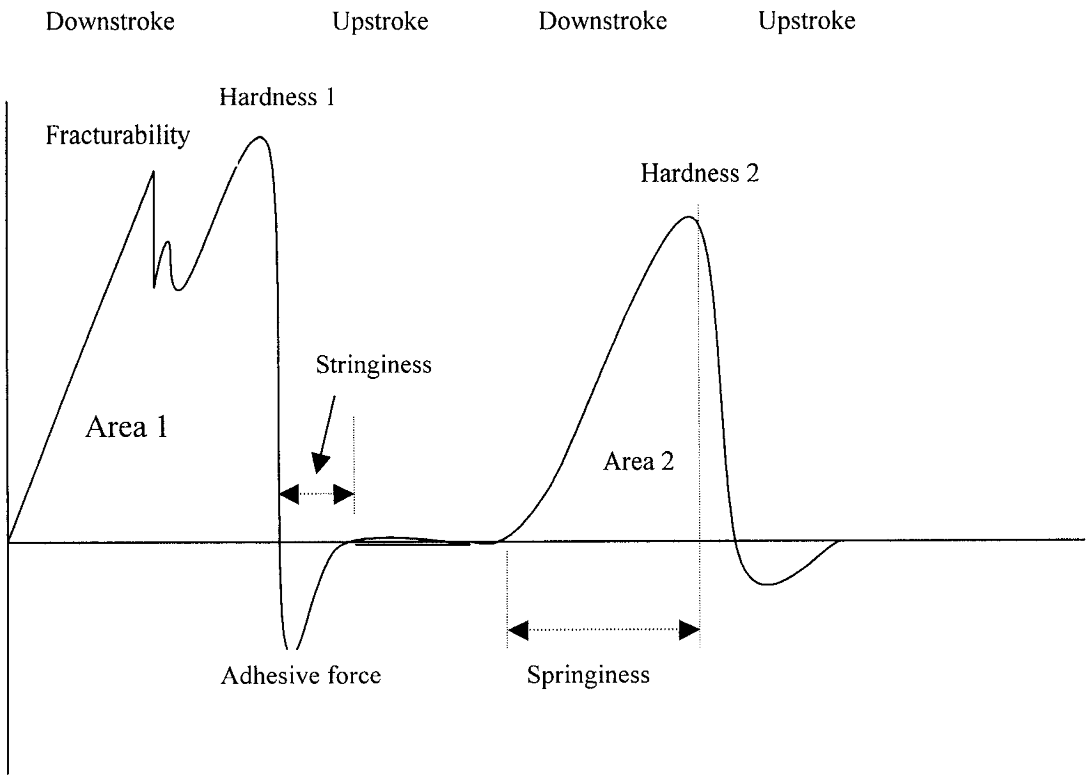

Figure 2.1 A typical TPA description curve (Peleg 1976)

Figure 2.1 shows a typical TPA curve. From this test, there are lots of useful information on noodle texture (Bourne 1995). For example:

1. Fracturability: Force at the first major drop in force curve. Popular terms describing fracturability are crumbly, crunchy, and brittle.

2. Hardness: Force at maximum compression. Popular terms describing hardness are soft, firm, and hard.

3. Adhesiveness: The tensile force, needed to pull food apart and separate it from the compression plates. Popular terms describing adhesiveness are sticky, tacky, and gooey.

4. Stringiness: The distance food extends before it breaks away from the compression plates.

5. Springiness: The distance or length of compression cycle during the second bite. Popular terms describing springiness are plastic and elastic.

6. Cohesiveness: The ratio of Area 2 divided by Area 1.

7. Gumminess: Multiplication of hardness and cohesiveness. Popular terms describing gumminess are short, mealy, pasty, and gummy.

8. Chewiness: Multiplication of gumminess and cohesiveness and springiness. Popular terms describing chewiness are tender, chewy, and tough.

Though Chewiness and Gumminess are similar, they are mutually exclusive. The same product cannot exhibit both Chewiness and Gumminess: Chewiness refers to solid foods and Gumminess refers to semi-solid foods (Szczesnaik, 1995).

2.2.1.3 Tensile test:

Tensile test is not widely used for food products because biting actions are normally compression, and not tension. However, for instant noodles, the tensile test is important because the eating utensil, normally chopsticks applies a tensile force to the noodles.

In one tensile test, each end of the noodle is wrapped several times around a mandrel-style grip. Friction holds the noodle to the mandrel while tensile force is applied. The texture analyzer records force and extension data from which tensile strength and percent elongation results are calculated (McManuis 2001).

Another example was done using the Stable Micro Systems/ Kieffer dough and Gluten Extensibility Rig, in which 10 g of flour can be used for six replications. It has been demonstrated that results obtained in micro extension trials can provide the same information as the macro methods.

2.2.2 Texture evaluation of cooked noodles

Desirable texture is essential for all kinds of noodle products. Instrumental measurement of cooked noodle texture can be a reliable and convenient alternative evaluation to the sensory method (Oh et al. 1983; Hou et al. 1997).

Oh (1983) suggested the basis on how to perform cutting and compression on cooked noodles. He found that the maximum cutting stress and the resistance to compression of cooked dry noodles were highly correlated with noodle firmness and chewiness, respectively. Later on, several works were done using the above methods or modified methods based on it (Baik 1994; Yun et al. 1997; Hou et al. 1997; Hatcher et al. 1999).

Hatcher et al. (1999) showed the influence of water absorption on the textural properties (recovery, resistance to compression, max. cutting stress and surface firmness) of alkaline and white salted noodles prepared from three types of Canadian wheat flour. The conclusion was that textural characteristics of white salted noodles significantly declined with increasing absorption levels; while alkaline noodles did not display distinct difference. In 2002, an attempt was made to exploit the effect of flour particle size and starch damage on noodle textures. This attempt showed that both factors did not affect the texture of raw noodles, but significantly affect the texture of cooked noodles.

Baik (1994) used TPA method to evaluate the starch and protein effect on several types of noodles. He found that high starch pasting properties and swelling power may be responsible for high quality of Japanese noodles, but they may be less critical to the quality of Cantonese and instant noodles. Meanwhile, Sodium Dodecyl Sulfate (SDS) of flours are highly correlated with the chewiness of noodles, which means that both protein content and protein quality are to be considered in predicting the textual properties of noodles. Later on, Yun et al. (1997) confirmed the above work by using large amount of samples of Japanese white salted noodles.

Epsteint et al. (2002) also used TPA to exploit the texture of white salted noodles from genetic level and concluded that starch composition is a major contributor to the texture of this kind of noodles.

For instant fried noodles, some researchers did some pioneer work on its textural properties by TPA method (Baik 1994; Hou 1997). Baik (1994) concluded that except for adhesiveness, TPA of noodles was a sensitive and reproducible test for the evaluation of oriental noodles, while Hou (1997) found that cohesiveness, hardness and chewiness of TPA were significantly correlated with the eating quality of cooked noodles. Also he concluded that cohesiveness is the most useful parameter for the evaluation of the eating quality of fried instant noodle.

2.2.3 Ingredient effect on noodle texture

Texture is a critical characteristic of noodles and many ingredients such as starch, water and protein, and additives like gum play important roles in governing textural properties. Therefore, their contributions to noodle texture are of great importance (Baik 1994; Edwards 1995 and Hatcher 1999). Hatcher (1999) found that the water absorption level had a major impact on processing and textural properties (recovery, resistance to compression, Max. cutting stress) of oriental noodles. White salted noodles revealed significant declines in textural characteristics with increasing water absorption. Starch properties are widely recognized as the most important determinant for the quality of Japanese white salted noodles. Lower amylose content, decreased number of branches in amylopectin molecules, high peak viscosity, low pasting temperature and high break down were associated with superior white salted noodles (Oda 1980, Toyokawa 1989, Batey 1997). Edwards (1995) found that addition of water soluble gum (Xanthan gum) contributed to the overall pasta firmness.

2.2.4 Correlation between textural properties and eating qualities of noodles

Instrumental measurement of cooked noodle texture can be a reliable and convenient alternative evaluation to the sensory method (Oh et al. 1983; Hou et al. 1997). By using an Instron Universal Testing instrument, Oh et al. (1983) found that the maximum cutting stress and the resistance to compression of cooked dry noodles were highly correlated with noodle firmness and chewiness, respectively. Hou et al. (1997) used texture profile analysis and reported that cohesiveness, hardness and chewiness were significantly correlated with the eating quality of cooked noodles. Also the analysis showed that cohesiveness is the most useful parameter for the evaluation of the eating quality of fried instant noodle.

2.3 RHEOLOGICAL PROPERTIES OF FOOD MATERIALS

The importance of rheology in the food industry cannot be over-emphasized. First, in the engineering aspects, most food materials are in the form of liquid or semi-solid. So for many food processing machines, the rheological properties of the materials are important. For pumping system, the selection and design of pump and pipeline is highly affected by the rheological properties of the fluids. And for pasteurization process (especially for aseptic processing system), the heat transfer to the fluid food is largely affected by the rheological properties of the fluids. Also, for other systems, such as mixer, extruder, homogenizer and so on, the rheological properties of the materials are very important (Steffe 1992).

Secondly, in sensory evaluation aspect, rheology also plays an important role. Recently, some cheese manufacturers attempted to develop low-fat cheeses. The low-fat cheeses should have the mimic sensory properties as full-fat cheeses. Rheological measurements have been successfully used to evaluate sensory characteristics of cheeses, such as firmness and springiness (Drake 1999).

Rheology is also important for on-line process control. Traditionally, on-line process control normally includes the control of temperature and mass flow of the intermediate products. With the development of rheology, the on-line process control of rheological properties is becoming popular. The online control of the dynamic viscosity is widely used in the production of chocolate and mayonnaise (Steffe 1996).

Recently, rheology has been used in many other fields. For instance, in protein research, many researchers used rheology to determine the temperature effect on the properties of proteins. They performed temperature sweep of different protein gels and found that each protein had a specific temperature point at which the G' value increases considerably. This temperature represents the denaturizing temperature of the protein gel (Gariepy 2002).

Foods are complex systems that can exhibit a wide range of different rheological behaviors, ranging from low viscosity fluids (e.g., milk) to hard solids (e.g., hard candy). Food rheologists have developed concepts that can describe these various types of rheological behaviors in terms of a few simple models such as the ideal solid and ideal liquid. Complex systems can then be described by combining two or more of these simple models (Steffe 1992)

2.3.1 Ideal solids

A material that exhibits ideal elastic behavior is called a Hookean solid after Robert Hooke first described it. Hooke found that there was a linear relationship between the deformation of an ideal solid material and the magnitude of the applied force. Hookes law can be summarized by the following equation:

$$\sigma = \varepsilon\gamma \tag{2.1}$$

The actual values of the stress (σ), strain (γ) and modulus of elasticity (ε) used in the equation depend on the nature of the deformation. Generally, there are three major types of deformation that are important. These are simple shear, simple compression and bulk compression. Each of these different types of deformation is characterized by its own stress-strain relationship.

2.3.2 Non-ideal solids

Hooke's law is only applicable to elastic materials at low strains, however, the rheological behavior of foods at large deformations is often more relevant to their actual use, e.g., mastication or cutting of foods. For this reason it is important to characterize the behavior of solids at large deformations. At strains above the Hookes region the stress is no longer proportional to the strain, and therefore an apparent modulus is used. It is always necessary to stipulate the strain at which the apparent modulus of a material is measured. Even though the material does not obey Hookes law it still returns to its original shape once the force is removed. Above a certain deformation, however, a solid may not return back to its original shape once the force is removed, because it either breaks or flows (Steffe 1996).

2.3.3 Ideal liquids

The ideal liquid is often referred to as a Newtonian liquid after Newton first described it. The rheological properties of the ideal liquid are expressed by the following equation, which shows that the rate of shear strain (γ) is directly proportional to the applied shear stress (τ).

$$\tau = \mu\gamma \tag{2.2}$$

The slope of the equation is called the viscosity (μ) which arises from the friction between the liquid layers. The lower the viscosity of a liquid, the less resistance between the liquid layers, and the faster the top plate moves when a given force is applied. For an ideal liquid, the viscosity is independent of the shear rate.

2.3.4 Non-ideal liquids

Non-ideal liquids may behave in various ways as follows depending on their flow characteristics.

2.3.4.1 Shear-rate dependent behavior

In many liquid foods the viscosity varies with the shear rate, but is independent of the time of shearing. In these kinds of foods, the viscosity is defined as an apparent viscosity, because it is no longer a constant. The dependence of the apparent viscosity on shear rate, means that it is necessary to select the shear rate used for the measurements. It is better to use a shear rate which is similar to that which the food actually experiences in practice. The two most common types of shear-rate dependent fluids are pseudoplastic fluids and dilatant fluids.

Pseudoplastic fluids: Pseudoplastic flow is the most common type of non-ideal behavior exhibited by liquid foods. It manifests itself as a decrease in the apparent viscosity of a fluid as the shear rate is increased, and is therefore referred to as shear thinning. Wheat flour dough normally shows shear thinning behavior (Berland 1995).

Dilatant fluids: Dilatant behavior is less common than pseudoplastic behavior. It manifests itself as an increase in the apparent viscosity as the shear rate is increased, and is therefore sometimes referred to as shear thickening (Steffe 1996).

2.3.4.2 Time-dependent behavior

Actually, there are many foods whose rheological properties also depend on the time of the applied shear. In some cases this change is reversible and the fluid will recover its original apparent viscosity if it is allowed to stand at rest for a sufficiently long period. In other cases the change brought about by shearing the sample is irreversible. Time-dependent flow properties of foods are of great practical importance in the food industry. The duration of pumping or mixing operations, for instance, must be carefully controlled to assure that the food sample has the most appropriate apparent viscosity. If a food is mixed or pumped for too long, it may become too thick or too runny and thus loose its desirable rheological properties. Time dependent non-Newtonian behavior in fluids is classified in two different ways namely thixotropic fluids and rheopectic fluids.

Thixotropic fluids: A thixotropic fluid is one in which the apparent viscosity decreases with time when the fluid is subjected to a constant shear rate. Fluids of this type are thought to contain small particles that are aggregated together by weak forces. Shearing of the material causes the aggregated particles to be disrupted and so they offer less resistance to flow and the viscosity decreases with time until a constant value is reached.

Rheopectic fluids: In some foods, the apparent viscosity of the fluid increases with time when it is subjected to a constant shear rate. Again there may be a number of different reasons for this. One of the most important is that shearing increases the frequency of collisions between particles in fluids which may lead to enhanced aggregation and later an increase in apparent viscosity.

2.3.5 Viscoelasticity

Viscoelastic materials exhibit both viscous and elastic behaviors simultaneously. When a force is applied to a viscoelastic material it does not deform instantly, and when the force is removed the material does not reform at the same time.

There are several ways of examining the viscoelastic properties of materials, but the commonest, and most versatile, is to use oscillatory rheology.

If a sinusoidal stress is placed on a solid sample, a sinusoidal displacement (strain) will be obtained which is in phase with the applied stress. The modulus of the material can be obtained by dividing the amplitude of the stress δ, by the amplitude of the strain γ. If a sinusoidal stress is applied to a liquid sample, the stress is in phase with the rate of change of strain, and a phase lag of 90° is therefore introduced between the stress and the strain.

For viscoelastic materials, the phase angle will be somewhere between 0° and 90°. The ratio of the stress to the strain amplitude therefore gives the stiffness of the material, and the phase angle describes its viscoelastic nature.

The usual method of performing an oscillation experiment is to apply a sinusoidal stress to a sample, over a range of frequencies, and to monitor the strain and phase angle. The stress is kept low so that it can be assumed that the unperturbed properties of the sample are determined. It is more usual to report the storage modulus, G', and loss modulus, G''. These are defined by the following equations:

$$G' = \left[\frac{\sigma_0}{\gamma_0}\right]\cos(\delta) \tag{2.3}$$

$$G'' = \left[\frac{\sigma_0}{\gamma_0}\right]\sin(\delta) \tag{2.4}$$

The advantage of these expressions is that G' represents the "solid" component of the material, and G'' the "liquid" component (Steffe 1992).

2.4 COMMONLY USED RHEOLOGICAL METHODS AND INSTRUMENTS

Foods are diverse materials which exhibit a wide range of different rheological properties, e.g., solids, liquids, plastics and viscoelastic behavior. Therefore, a variety of different instruments have been developed for characterizing their rheological properties. Instruments vary according to the type of deformation they apply to the sample (shear, compression, elongation or some combination), the property measured, the cost, the ease of operation etc (Steffe 1992).

From the application aspect, it is necessary to have instruments which make measurements that are rapid, low-cost, simple to carry-out and reproducible, thus simple empirical instruments are often used, rather than the sophisticated and expensive instruments often used in research and development. The information obtained from these instruments is difficult to relate to the fundamental rheological properties of a material because the stresses and strains applied are not easily defined. Rather than having a simple tension, shear or compression, different types of forces may be applied simultaneously. To compare data from different laboratories, it is necessary to carefully follow standardized test procedures. These procedures may define experimental parameters such as the sample size and preparation procedure, the magnitude of the force or deformation, the design of the device used, the speed of the probe, the length of time the force is applied for and the temperature measurement.

From the research aspect, it is more important to use instruments that provide information about the fundamental rheological parameters. These instruments are designed to apply well-defined stresses and strains to a material in a controlled manner so that stress-strain relationships can be interpreted using suitable mathematical analysis. Rheological properties determined using these techniques can be compared with measurements made by other workers in the literature or in other laboratories. In addition, measured rheological properties can be compared with predictions made using various mathematical theories that have been developed to relate the structure and composition of materials to their fundamental rheological properties. There is an increasing trend in the food industry to use instruments that provide more fundamental data.

Instruments can be conveniently categorized according to whether they utilize simple compression, elongation or shear forces.

2.4.1 Simple compression and elongation

These types of measurements are most frequently carried out on solid or semi-solid foods that are capable of supporting their own weight. Fundamental measurements are usually carried out using instruments referred to as Universal Testing Machines. The solid sample to be analyzed is placed between a fixed plate and a moving probe. The probe can have many different designs depending on the type of information required. Some of the most commonly used designs include: a flat plate, a blade, a cylindrical spike or a set of teeth. The type of probe used may also depend on whether or not the analyst is trying to mimic some actual process, *e.g.,* chewing, biting or cutting. The probe can be moved vertically, either upwards or downwards, at a controlled speed. The lower plate usually contains a pressure sensor that measures the force exerted on the sample when it is deformed by the probe. Thus the instrument measures both the stress and strain on the sample as it is compressed.

By using different fixtures the same instruments can be used to carry out tensile experiments. A sample is clamped at both ends, then the upper clamp is moved upwards at a controlled speed and the force required to elongate the sample is measured. Then the elastic modulus and breaking strength can be determined (McManuis 2001).

2.4.2 Shear test

Instruments that measure shear are used to characterize the rheological properties of liquids, solids and viscoelastic materials. The instrument and test-method used depends on the nature of the sample to be analyzed. Some instruments are only useful for low viscosity ideal liquids, others for solids, and others can be used for a wide range of different materials. Some instruments are capable of measuring the viscosity over a wide range of shear rates, whereas others make the determination at a single shear rate, therefore only suitable for analyzing Newtonian liquids. To make accurate and reliable measurements it is important to select the most appropriate instrument and test method, and to be aware of possible sources of experimental error.

2.4.2.1 Simple viscometers

The simplest and most commonly used viscometer is the capillary viscometer. This consists of a glass U-tube into which the sample to be analyzed is poured. The whole arrangement is placed in a water bath to reach the measurement temperature. The viscosity of the liquid is measured by sucking up liquid into one of the arms and then measuring the time taken for it to flow back through a capillary of known radius and length. The time t taken to travel through the capillary is related to the viscosity (Steffe 1992).

This type of viscometer is used principally to measure the viscosity of Newtonian liquids. It is unsuitable for analyzing non-Newtonian liquids because the sample does not experience a uniform and controllable shear rate. U-tubes with capillaries of various diameters are available to analyze liquids with different viscosities: the larger the diameter, the higher the viscosity of the sample that can be analyzed.

2.4.2.2 Mechanical viscometers and dynamic rheometers

A number of analytical instruments have been designed that can measure the shear properties of liquids, viscoelastic materials, plastics and solids. These instruments are usually computer controlled and can carry out sophisticated test procedures as a function of time, temperature, shear rate or frequency. Most of these instruments can be adapted to carry out tests using either the concentric cylinder, cone-and-plate or parallel plate arrangements discussed below. All of these arrangements can be used to measure the viscosity of liquids, the viscoelasticity of semi-solid foods or the elasticity of solids. The instruments can be divided into two different types namely constant stress and constant strain instruments. Constant stress instruments apply a constant torque to the sample and measure the strain or rate of strain generated, whereas constant strain instruments apply a constant strain or rate of strain and measure the torque generated in the sample.

Concentric cylinder: The sample is placed in the gap between two concentric cylinders. The inner cylinder is then driven at a constant torque and the strain or rate of strain is measured. For a solid, the strain of the inner cylinder from its rest position is an indication of its elasticity; the larger the strain, the smaller the shear modulus. For a liquid, the viscosity of the fluid between the plates governs the speed at which the inner cylinder rotates: the faster it spins at a given torque the lower the viscosity of the liquid being analyzed. The torque can be varied in a controlled manner so that the (apparent) elastic modulus or viscosity can be measured as a function of shear stress. This instrument can be used for measuring the viscosity of non-Newtonian liquids, the Viscoelasticity of semi-solids and the elasticity of solids.

Parallel plate: In this instrument the sample is placed between two plates; the bottom plate is stationary while the top plate rotates. A constant torque is applied to the upper plate, and the angular deflection or rate of strain is measured, depending on whether one is analyzing a predominantly solid or liquid sample.

Cone and plate: This is essentially the same design as the parallel plate instrument, except that a cone replaces the upper plate. The cone is specially designed to have a slight angle so that there is a constant shear strain across the sample.

Cone and Plate and Parallel Plate are commonly used for the transient and dynamic rheological tests of dough because they are suitable to semi-solid materials (Lindahl 1992; Miller 1999; Watanabe 2002).

2.4.3 Empirical techniques

A large number of highly empirical techniques have been developed by food scientists. Many of these empirical techniques have become widely accepted for analyzing specific food types. Typical examples may be penetrometers to measure the hardness of fats, specially designed guillotines for analyzing meat samples, devices for measuring the flow of sauces when released from a cup etc. It is difficult to analyze the data from these devices using fundamental concepts because it is difficult to define the stresses and strains involved. Nevertheless, these devices are extremely useful where rapid empirical information is required. For dough rheological test, Farinograph, Mixograph, Extensigraph and Alveograph are normally used (Steffe 1996).

2.5 INFLUENCE OF INGREDIENTS EFFECTS ON DOUGH RHEOLOGY

Several factors affect the results obtained by dynamic mechanical testing of doughs. Increasing oscillation frequency has been shown to increase G' and G'' of flour doughs. Conversely, increasing strain amplitude tends to reduce G' and G'' (Smith et al. 1970). Moisture content has been demonstrated to have a strong influence on elasticity and viscosity of products being tested. Both G' and G'' decreased with increasing moisture content (Hansen et al. 1991 and Navickis et al. 1982). Protein content of doughs has been observed to affect dynamic moduli, indicating higher moduli as protein content increases (Navickis et a1. 1982).

2.5.1 Protein

Strong dough, which has high resistance and extensibility in the extensigraph, provides firmer and more elastic noodles than do weaker flours. Flours with protein content below 9.5% have been found to give raw Chinese noodles a satisfactory eating quality (Miskelly and Moss 1985). The viscoelastic properties of dough are, to a large part, governed by the rheological properties of the gluten. Abdelrahman (1986) found that the addition of gluten led to the increase of both G' and G'' and the decrease of $\tan\delta$. The relationship between the amount of gluten added and the increase in G' was linear. Interaction between protein and starch also plays an important role in dough rheology (Petrofsky 1995). From the genetic level, the high molecular weight glutenin sub-units (HMW-GS) play an important role in governing the functional properties of wheat dough. Rheological properties such as elongation, dynamic, and shear viscometric properties were determined. The presence of Glu-D1 sub-units (5+10) made a significantly larger contribution to dough properties, such as strength and stability, than those encoded by Glu-B1 (17+18) (Uthayakumaran 2002).

2.5.2 Starch

Starch can affect dough rheology in a variety ways. Starch content, gelatinization and protein-starch interaction are major factors that contribute to the difference in dough rheology. Addition of starch led to the increase of both G' and G'' and decrease of $\tan\delta$. However, the relation between the amount of starch added and the increase in G' was non – linear (Abdelrahman 1986)

The effect of gelatinized starches from different species on dough rheology had been found by Lindahl et al. (1992). Adding pre-gelatinized starch to a gluten-starch mixture resulted in an increase in G' and a decrease in $\text{Tan}\,\delta$, similar to the change caused by heating. Shiau (2001) also confirmed that gelatinization of starch caused a remarkable increase in G' and reduce the difference in G' and $\tan\delta$.

Soft wheat and non-wheat starch dough had higher moduli when compared to the hard wheat starch, possibly due to the greater starch-gluten interaction (Petrofsky 1995).

Gluten-water dough has smaller elastic modulus than does flour-water dough. This appears to show that starch act as filler in the polymer to show a larger modulus than unfilled counterparts (Hoseney 1993).

2.5.3 Water

There is a need for a method that strongly predicts the optimum water absorption for flour noodle making. The amount of water used for noodle making is limited compared to that for bread-making. The amount of added water depends principally on the flour protein content. particle size, starch damage, and pentosans (Oh et al. 1985).

Oh et al. (1985) varied water absorption from 30 to 38% in the production of long, dry noodles and water absorption was found to affect noodle color, wet strength, and dry strength. Furthermore, when absorption was varied more than 2 or 3% from optimum, sheeting, cutting, and drying of noodles became difficult.

Mixogram curve were used by (Oh et al. 1986) to predict the optimum water absorption of flour for production of oriental noodles. Increments of water were made each minute to flour (10 g) in the mixograph until the width and height of the mixogram increased significantly. The mixogram absorption at this point was 4-8% higher than that determined by the "handling" properties of dough to produce long, dry noodles.

Dynamic rheological test has been used to find the relationship between water level and dough rheological parameters. Some earlier works had expressed the relationship of G' and G'' to water content (Nawickis et al. 1982 and Dreese et al. 1988). The conclusion is that both G' and G'' decrease as the water content of dough increased. Later work confirmed the result (Abdelrahman et al. 1986; Berland et al. 1995; Beasley et al. 2000 and Srinivasan et al. 2000).

However, the conclusion of the moisture effect on the tan δ value was inconsistent. Abdelrahman et al. (1986) performed the rheological test using DMS (Dynamic Mechanical Spectrometer) with parallel plate and indicated that as the water level increased from 50 to 58%, the loss tangent of dough (without rest) increased gradually; when the water level was increased above 58%, the loss tangent decreased sharply. He also found that after the dough rested 30 minutes, the loss tangent increased for the range of the water levels of dough (50 - 60%). On the other hand, Berland et al. (1995) used a controlled stress rheometer with a cone-plate geometry and concluded that

$\tan\delta$ was independent of water content when dough water content varied between 43.8 and 49.4%. This result was consistent with Hibberd (1970), Hibberd et al. (1975), Navickis et al. (1982), and Dreese et al. (1988). A modified result was reported by Beasley et al. (2000), who concluded that increased water content (59-69%) led to decreases in dynamic rheological properties such as storage modulus, loss modulus and phase angle.

Edwards et al. (1996) concluded that water absorption strongly affected dynamic rheological results of noodle dough. G' decreased with increased moisture (28, 30, 32, 34%) for all noodle dough type (1% NaCl, 1% kansui, 1% NaOH and without additives).

2.5.4 Gum

Gum is normally used together with starch to improve the quality and stability of cereal food. The effect of gum on dough rheology is a relatively new topic. Rosel (2001) investigated the effect of different hydrocolloid gums (sodium alginate, k-carrageenan, xanthan gum and hydroxypropylmethylcellulose) on the rheological properties of wheat flour dough using several empirical instruments (farinograph, extensograph, alveograph and rheofermentometer). Xanthan and alginate had the most pronounced effect on dough properties yielding strengthened doughs. Shi et al. (2002) investigated the effect of food gums on viscosity of starch suspensions during pasting with a Brookfield viscometer. A viscosity increase before the normal starch pasting temperature was detected for normal maize starch in the presence of carboxymethylcellulose (CMC), gellan, xanthan, guar gum, and sodium alginate. It appeared that interactions between certain leached molecules, primarily amyloses, and certain gums were responsible for the viscosity increase occurring before starch pasting. Sudhakar (1996) found that the addition of salts to starch alone as well as starch-guar gum combinations caused a decrease in flow behaviour index, suggesting that both guar gum and salts make the starch pastes more pseudoplastic.

2.6 CORRELATION BETWEEN DOUGH RHEOLOGY AND QUALITIES OF NOODLES

Edward et al. (1996) investigated the rheological properties of noodle dough prepared from three types of Canadian wheat flour and its relationship to water absorption, formulation and work input during dough sheeting. Hatcher et al. (1999) showed the influence of water absorption on the processing characteristics such as raw thickness, sheet length, cooking time and cooked thickness and total work required, color and textural properties (recovery, resistance to compression, max. cutting stress and surface firmness) of alkaline and white salted noodles prepared from three types of Canadian wheat flour. Yeh et al. (1999) and Shiau et al. (2001) studied the effects of oxido-reductants and Alkali-acids on rheological properties of wheat flour dough and compared the correlation between rheological properties of dough and texture and cooking properties of extruded noodles. It showed that the dough rheology significantly correlated with the characteristics of extruded noodles at low temperatures. When the temperature was raised to 80°C, only the loss tangent negatively correlated with both tensile strength and cutting force. The results indicated that extrusion would be appropriate for producing noodles at low temperatures.

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CHAPTER 3: RHEOLOGICAL PROPERTIES OF NOODLE DOUGH AS AFFECTED BY SOME INGREDIENTS

3.1 CONNECTING STATEMENTS

In this chapter, the rheological properties of instant noodle dough under different levels of ingredients such as moisture, gum and starch were studied. Rheological properties of dough provide useful information on predicting quality characteristics of bread, noodles and other cereal products. However, there is limited information on the rheology of instant noodle dough. The study in this chapter is the first step to investigate the fundamental and dynamic rheological properties of instant noodle dough and provide information for further studies.

The result of this study has been presented at the CSAE 2003 annual conference: *Li Juan Yu and Michael Ngadi. 2003. Rheological properties of instant fried noodle dough.*

3.2 ABSTRACT

The rheological properties of noodle dough are affected by certain ingredients namely moisture content, gum content and starch addition. The results indicated that increasing moisture content caused significant decreases in the Young's modulus (E), energy at break (EB) and storage modulus (G') but caused an appreciable increase in the phase angle (δ). In addition, increasing moisture content caused a decrease in the energy at break (EB) at low starch addition level while it resulted in an appreciable increase in the EB at higher starch addition level. Increasing gum content significantly caused increases in Young's modulus, energy at break as well as the storage modulus, particularly at higher moisture level. Starch addition level, when increased resulted in an increase in the storage modulus but this was less significant than moisture and gum effects. Interaction effects between water, gum and starch on some rheological parameters were also observed. Furthermore, increasing gum and starch interactions led to a decrease in the energy at break while increasing interactions between gum and moisture caused an increase in the Young's modulus.

3.3 INTRODUCTION

Dough is a complex network made up of flour, water and other ingredients. Its structure and properties vary, depending on desired cereal products such as breads, pastas, biscuits and noodles. Noodles differ widely in composition, method of preparation and presentation depending on preference. For instance, common ingredients in oriental noodles include sodium chloride, kansui (mixture of sodium and potassium carbonates) and occasionally NaOH, in combination with flour and water (Edwards et al. 1996). Many types of noodles are produced throughout the world. In their simplest form, wheat noodles are a type of pasta prepared from a dough containing flour, water and salt (Oh et al. 1986).

Several studies have shown that water content play a large role in determining doughs viscoelastic properties. It has been well established that both the storage modulus (G') and loss modulus (G'') decrease as water content of dough is increased (Hibberd 1970; Hibberd and Parker, 1975 and Navickis et al. 1982). This finding was later supported by Abdelrahman et al. (1986), Berland et al. (1995), Edwards et al. (1996), Beasley et al. (2000) and Srinivasan et al. (2000).

Starch is an important composition in the noodle dough than in other types of dough including bread dough because it is typically in a relatively higher concentration in the noodle dough. Gum is an additive that is most commonly used in instant fried, noodle dough than in other types of dough. It is normally used together with starch. Rosel (2001) used several empirical instruments (farinograph, extensograph and alveograph) to investigate the effect of hydrocolloid gums (sodium alginate, K-carrageenan, xanthan gum and hydroxypropylmethylcellulose) in the rheological properties of wheat flour dough. The author reported that Xanthan and alginate had the most pronounced effects on dough properties such as yield strength. Rheological properties of doughs are affected by many factors such as ingredients and processing procedures. They are traditionally determined by using mixing instruments such as alveograph or Farinograph (szczeniak 1963). Other measurement techniques based on fundamental and dynamic rheometry has been used to assess the characteristics of bread, pasta and noodle dough (Irvine et al. 1961; Dexter and Matsuo 1980; Cubadda 1988; Oliver et al. 1995; Shiau and Yeh 2001).

The objectives of this study were to determine the influence of three (3) ingredients namely moisture, starch and guar gum, on fundamental and dynamic rheological properties of instant fried noodle dough and to determine the relationships between these properties.

3.4 MATERIALS AND METHODS

3.4.1 Materials and dough preparation

Unbleached, baker's patent flour, milled from the Canadian Hard Red Spring wheat was used in the experiment. Composition of the flour was as follows: 14% moisture; 0.53 – 0.58% ash; 13.0 – 14.0% protein and the granulation was 100% finer than 149 microns (100 meshes US). The starch that was used was a food grade specialty potato starch, which had a low gelatinization temperature of 57°C, good dispersion in cold, lipid and hot liquids, and a low tendency to retrogradation. The guar gum was in powder state. The guar gum powder was first distributed in water by using a stirrer (Corning Stirrer/hotplate, PC-520, Corning Inc, Corning, NY) at room temperature; then stored for approximately 12 hrs at room temperature; stirred again until distributed uniformly.

The instant noodle was formulated by mixing 100% flour (14% moisture content); 1.5% (kg/kg flour) salt; 0.1% (kg/kg flour) alkaline salt (mixture of potassium carbonate and sodium carbonate); 0 – 0.3% (kg/kg flour) gum; 0 – 7.5% (kg/kg flour) starch and 30 – 36% (kg/kg flour) water. In the following chapters, gum, starch and water addition% (kg/kg flour) were simplified to gum, starch and water%. Mixing of the noodle dough was done by electric pasta machine (ATLAS 182 Electric Pasta Maker, OMC Marcato, Italy). The flour (300 g) mixed with starch was added to the mixing container of the pasta machine. Water solution of dissolved salt, alkaline and guar gum was added to the flour mix in the pasta machine. The pasta machine was then operated intermittently for 1 and 3 min. until the dough was properly and evenly formed. The dough was removed from the pasta machine and cut into three uniform small pieces. The dough was passed through the roller unit attachment with the regulating knob set at No.1 position (2.5 mm). The resulting sheet was folded into two and passed again through the rollers. This process was repeated several times until the dough sheet was smoothly formed. The dough sheet was then placed in a covered box until used for tests after allowing 30 min rest for the samples.

3.4.2 Fundamental test

Fundamental rheological tests were conducted using the Instron Universal Testing Machine (Model 4201, powered by Instron Series IX software (Automated Materials Testing System, V.5) Instron Limited, England) with a Kramer shear cell attachment, to provide a combined compression and shear test. Noodle sheets of dimension 2.5 mm (thickness), 66 mm (width) and 66 mm (length) were used. A 50 kN load cell was used and the crosshead speed for all tests was 120 mm/min. Several parameters were obtained, including Young's modulus, maximum load, load and energy at break point. All the tests were carried out in three repetitions. Average values were calculated and used for further statistical analysis.

3.4.3 Dynamic test

Dynamic rheological tests were conducted using a controlled rate rheometer (AR2000, TA Instruments, New Castle, DE) operated with parallel plate geometry of 40 mm diameter. Preliminary test was made by performing a strain sweep (0.001 to 10%) at a frequency of 1 Hz, which showed a linear viscoelastic region of the noodle dough below the strain value of 1.0%. Therefore dynamic oscillatory measurements were made at a strain of 0.03% with a frequency sweep between 0.5 and 5 Hz. The data for the analysis were collected at a frequency of 1 Hz. The test was done immediately after the noodle disk (cutting from noodle sheet of dimension 2.5 mm thickness and 40 mm diameter) was brought out from the box, and lubricated with oil to avoid drying of the disk during test. Relevant rheological parameters were obtained, including storage modulus (G'), loss modulus (G'') and phase angle (δ). These parameters were obtained by using the software analysis program of the rheometer. All the tests were carried out in three repetitions and the average values were calculated and used for further statistical analysis.

3.4.4 Data analysis

The analysis was carried out using the GLM procedure of SPSS (SPSS for Windows, release. 8.0.0. SPSS Inc. Chicago, IL).

3.5 RESULTS AND DISCUSSION

3.5.1 Effect of ingredients on the fundamental rheological properties of instant noodle dough

3.5.1.1 Young's modulus (E)

Statistical analysis of data showed that gum and moisture additions significantly ($P < 0.05$) affected Young's modulus (E) for noodle dough. Similarly, their interactions also affected Young's modulus. However, there was no significant effect of starch on the Young's modulus.

Figure 3.1 shows the interaction effects of gum and moisture addition on Young's modulus (E). It was observed that at 30 and 32% moisture content value, the Young's modulus increased as the gum content was increased from 0 to 0.1. But at higher moisture content values of 34 and 36%, the Young's modulus did not show any significant changes. The above results indicated that gum as a hydrocolloid substance was able to exert a greater binding influence on moisture and form strong films which might have resulted in increased Young's modulus at the lower moisture content values of 30 and 32%. As the moisture content was increased to 34 and 36%, this influence steadily diminished.

When the gum addition was increased from 0.1 to 0.2%, it was observed that Young's modulus decreased at 30 and 32% moisture levels. But as the moisture content was increased to 34 and 36%, Young's modulus was partially stable with only a slight decrease at 34% moisture content. This indicated that further addition of gum to water particularly at 30 and 32% moisture might have reinforced the presence of gum in a proportion that was sufficient to bind a substantial quantity of moisture but insufficient to fully exert the influence of gum over moisture. This interacting development might have resulted in the significant decrease in Young's modulus (E) which is also a measure of the elastic property of noodle dough. However, this effect was not significantly observed at higher moisture values due to a greater presence of water which stabilized the value of Young's modulus by acting against the initial decreases.

At 0.3% gum addition level, it was observed that the Young's modulus increased for all levels of moisture addition ie 30, 32, 34 and 36%. This implied that the interaction effects of gum and moisture additions was sufficient to fully exert the elastic characteristics of the noodle dough and hence caused increased Young's modulus (E).

3.5.1.2 Energy at break point (EB)

Energy at break point (EB) is related to the work needed to push the dough sheet through the kramer shear cell cavity. It combines viscous and elastic properties of dough. Moisture content and starch addition level significantly ($P < 0.05$) affected energy at break point as indicated by the statistical analysis of data. The result shows that moisture content and starch contributed to the viscoelastic properties of dough. Gum showed no effect on energy at break. However, there were significant effects ($P < 0.05$) of water-gum, starch-gum and water-starch interaction on EB.

Figure 3.2 shows the relationships between energy at break and the moisture content of noodle dough as affected by different levels of starch addition. When the moisture content was increased from 30 to 32%, the energy at break (EB) decreased for starch addition levels at 0, 2.5% and 5.0%. But for starch addition level at 7.5%, the EB increased when the moisture content was raised from 30 to 32%. The decreases observed at starch addition levels 0, 2.5 and 5% could be attributed to the inability of the added starch quantity to fully exert its functionality as an hydrocolloid substance over moisture, hence the reduction in EB. However, as the added starch quantity was increased to 7.5%, the effect of starch became more pronounced, leading to an increase in the value of EB.

When the moisture content of noodle dough was increased from 32 to 34%, the energy at break increased for starch addition levels at 0 and 2.5%. For starch addition level at 5.0%, EB slightly reduced while it increased significantly for starch addition level at 7.5%. The increases observed particularly at 2.5% starch addition level could be attributed to the primary hardening of the dough by the starch. As the starch addition level was increased to 5.0%, the viscoelastic characteristics of the dough became more significant with greater influence by moisture presence which led to a slight reduction in EB. A further increase in the level of starch addition to 7.5% finally created an enabling environment for starch to exert its functionality over moisture, thereby causing EB to increase.

When the moisture content of noodle dough was increased from 34 to 36%, the energy at break decreased for starch addition levels at 0 and 2.5%. For starch addition at 5%, EB increased significantly while 7.5% starch addition level pronounced a slight increase in EB. These results indicated that the decreases recorded at 0 and 2.5% starch addition level did not create enough effect on moisture activity at 36% moisture level. As the starch addition level was increased to 5.0%, a viscoelastic development arising from moisture-starch interaction was created. This led to a more pronounced activity of starch over moisture thereby causing an increase in EB. A further increase in the starch addition level to 7.5% similarly caused a slight increase in the value of EB.

Figure 3.3 shows the relationship between the energy at break (EB) and gum addition for noodle dough as affected by different levels of water addition. When the gum content was increased from 0 to 0.1%, the energy at break (EB) decreased with moisture level at 30%. But at moisture level 32, 34 and 36%, EB increased with increasing gum content. This indicated that at 30% moisture addition, enough interactions could not be established between gum and moisture, possibly because of insufficient quantity of either gum or moisture in the dough. This might have consequently led to an isolated effect of moisture on the energy at break. However, as the moisture level was increased to 32, 34 and 36%, a greater interaction was established between moisture and gum hence EB increased significantly.

When the gum content increased from 0.1 to 0.2%, the energy at break significantly decreased with moisture content level at 30%. With increasing moisture content to 32%, EB slightly increased. But as the moisture content was further increased to 34%, EB slightly decreased while it significantly increased at 36% moisture content. The above results generally indicated different levels of gum and moisture interaction based on their relative percentage quantities and how this relates to EB. Specially, viscoelastic conditions that favor greater moisture effects as recorded for 30 and 34% moisture levels resulted in a increase in EB while those that favor greater gum influence as indicated for 32 and 36% moisture levels resulted in increased EB.

With increasing gum content from 0.2 to 0.3%, EB decreased with moisture addition levels at 30 and 34%. However, EB increased at 32 and 36% moisture addition levels. This suggested an indication of moisture and gum interaction effect on EB through varying viscoelastic conditions.

Figure 3.4 shows the effects of gum and starch on energy at break. AT 0% starch addition, the EB increased with increasing gum content from 0 to 0.1, 0.2 and 0.3%. This supported the fact that gum addition promotes the viscoelastic characteristics of noodle dough, thereby increasing the EB value. At 2.5% starch addition level, EB increased with increasing gum content from 0 to 0.1 and 0.2% but decreased at 0.3% gum addition. This suggested that the interaction between starch and gum attained a turning point which corresponded to an optimum EB value. It also suggested that any further starch addition at this point would only indicate a reduction in the value of EB.

At 5% starch addition level, the EB increased with increasing gum content from 0 to 0.1%. When the gum content was increased to 0.2 and 0.3%, the energy at break steadily decreased. This indicated a shift in the gum-starch interaction level and it further implied that there is always a maximum value of EB for each gum-starch interaction level after which the EB steadily decreased.

At 7.5% starch addition level, the energy at break increased with increasing gum content from 0 to 0.1% but decreased when the gum content was further increased to 0.2 and 0.3%. This supported the earlier indication about gum and starch interaction in relation to energy at break.

3.5.2 Effect of ingredients on the dynamic rheological properties of instant noodle dough

3.5.2.1 Storage modulus (G')

Storage modulus (G') is one of the most important parameters in dynamic test. It relates to the solid property part of semi-solid food products. There was a significant effect of moisture content ($P < 0.05$) and gum addition level ($P < 0.05$) on storage modulus (G') as shown in figure 3.5. Starch effect on storage modulus was also significant (P < 0.05) but less pronounced than moisture and gum effects.

Figure 3.5 shows the effect of moisture and gum on storage modulus for noodle dough. At 0, 0.1, 0.2 and 0.3% gum addition levels, storage modulus (G') significantly decreased as the moisture content was increased from 30 to 32, 34 and 36%. This result was consistent with some earlier reports (Abdelrahman et al. (1986); Berland et al. (1995); Beasley et al. (2000)).

Figure 3.6 shows the effect of starch on storage modulus for noodle dough. With increasing starch addition level from 0 to 2.5, 5.0 and 7.5%, the storage modulus (G') increased significantly. This could be attributed to the fact that starch, like gum is an hydrocolloid substance that shares certain similar characteristics with gum. This implied that starch and gum could possibly affect noodle dough properties in a similar manner which in this case was to increase the value of G' with increasing starch addition.

3.5.2.2 Phase angle (δ)

The phase angle is equal to the ratio G''/G'. It varies in direct proportion to the liquid characteristics and in reverse proportion to the solid characteristics of viscoelastic materials including the noodle dough. There was a significant effect of moisture content (P < 0.05) on phase angle.

Figure 3.7 shows the effect of moisture content on phase angle (δ). With increasing moisture content from 30 to 32%, the phase angle decreased slightly but as the moisture content was further increased to 34 and 36%, the phase angle significantly increased. The initial decrease in the phase angle could be attributed to the fact that the moisture contents at 30 and 32% were insufficient to exert enough functionality in the dough. This was however made possible when the moisture content was subsequently increased to 34 and 36%.

3.6 CONCLUSION

From the proceeding discussions and analysis of results, it could be summed up that ingredients namely moisture content, gum content and starch addition level caused significant effects on the rheological properties of noodle dough.

Gum and moisture content as well as their interaction significantly affected the Young's modulus (E) for noodle dough. At lower gum and moisture content, E decreased with increasing gum and moisture interaction level. But as the gum and moisture content increased, the Young's modulus increased significantly with increased gum and moisture addition.

At lower moisture and starch interaction level, there was little or no effect on the energy at break (EB). But as the starch addition became higher, there was an indication of primary hardening of the noodle dough. However as the starch addition level was further increased, there was a more pronounced effect of starch which caused a significant increase in the energy at break.

Viscoelastic conditions of moisture and gum interactions that favor greater moisture effects as observed for 30 and 34% moisture contents resulted in a decrease in energy at break while those that favor greater gum influence as indicated for 32 and 36% moisture level resulted in increased EB.

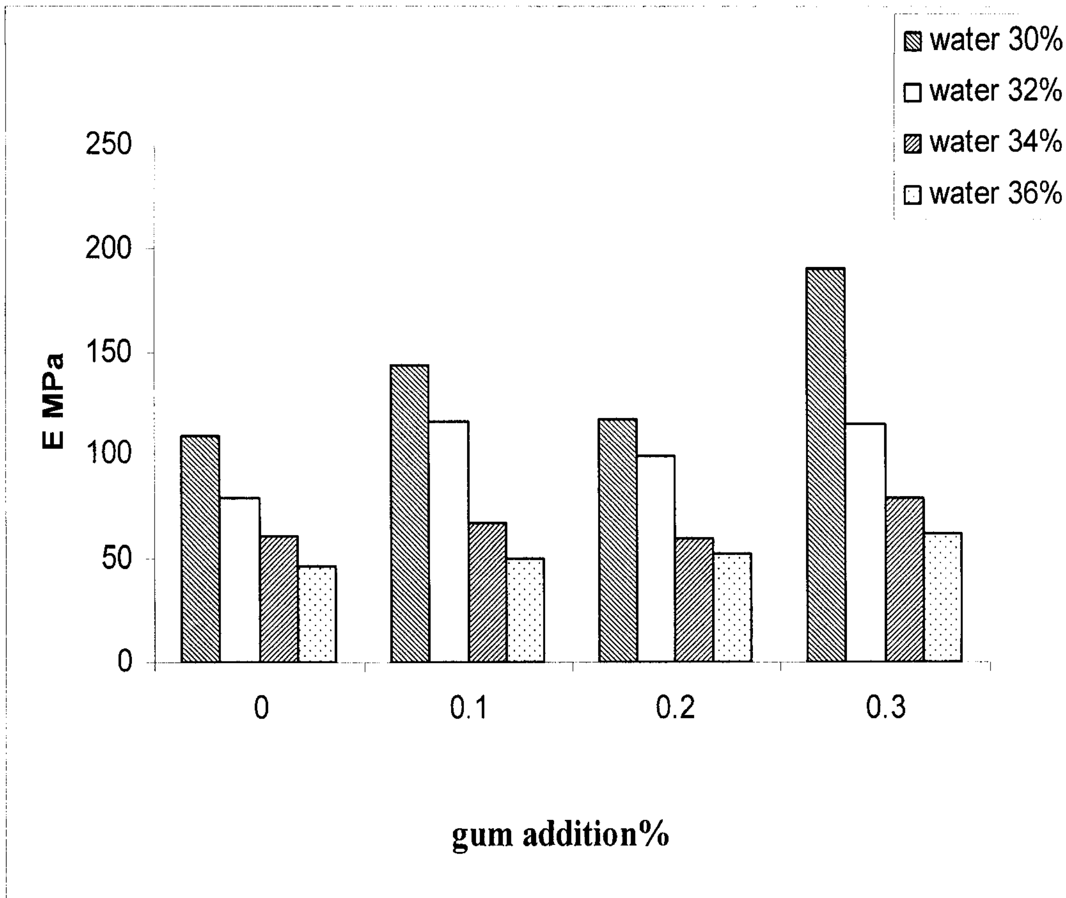

Fig. 3.1 Effect of moisture and gum on Young's modulus (E) for noodle dough

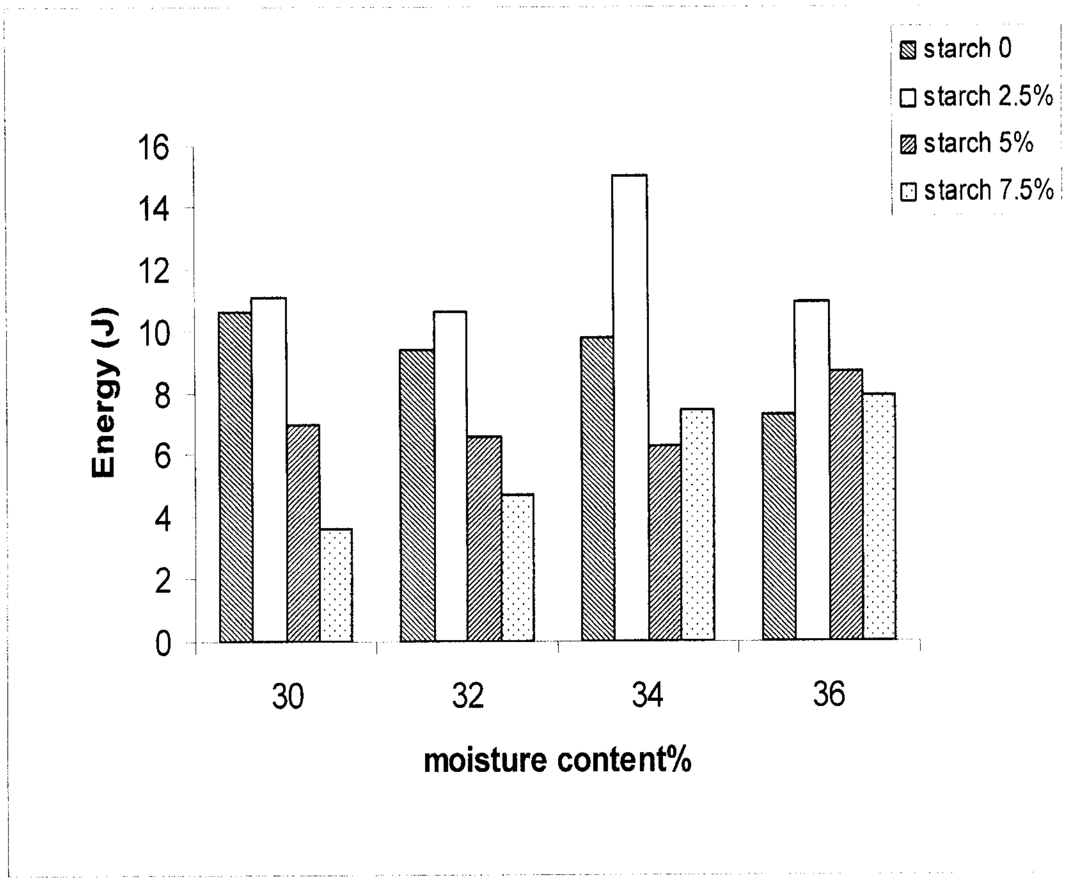

Fig. 3.2: Effect of moisture and starch on Energy at break for noodle dough

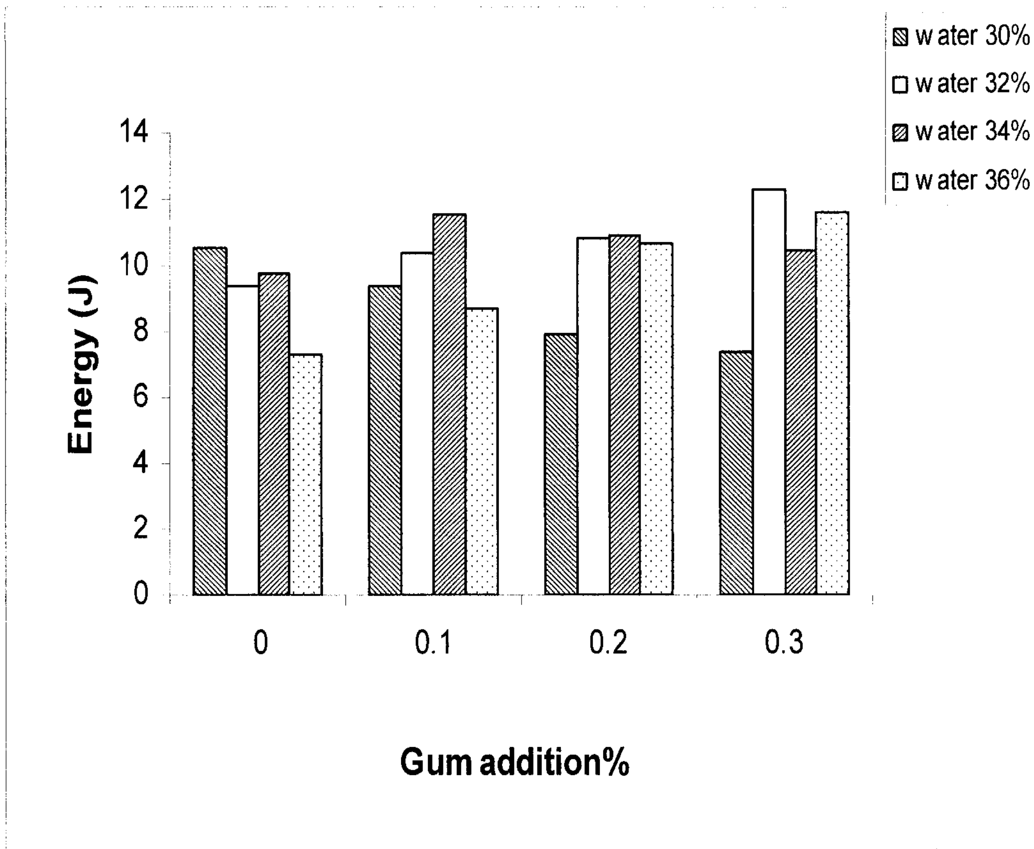

Fig. 3.3 Effect of moisture and gum on Energy at break for noodle dough

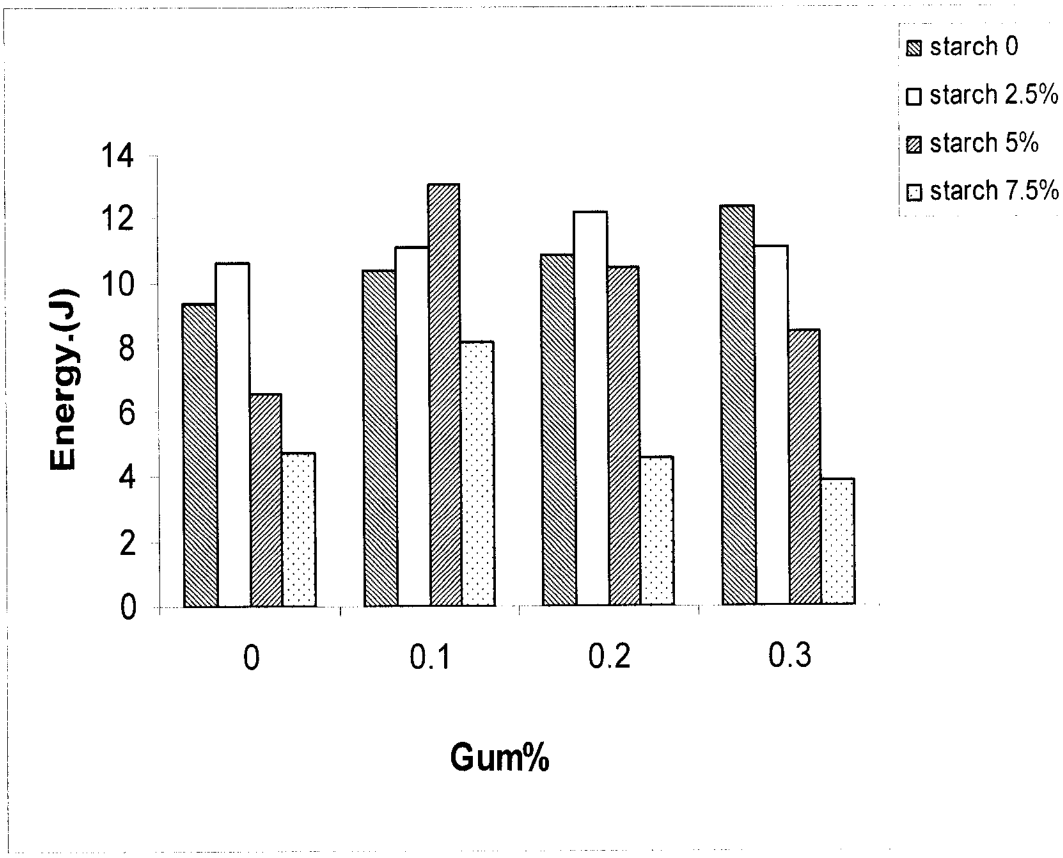

Fig. 3.4 Effect of starch and gum on Energy at break for noodle dough

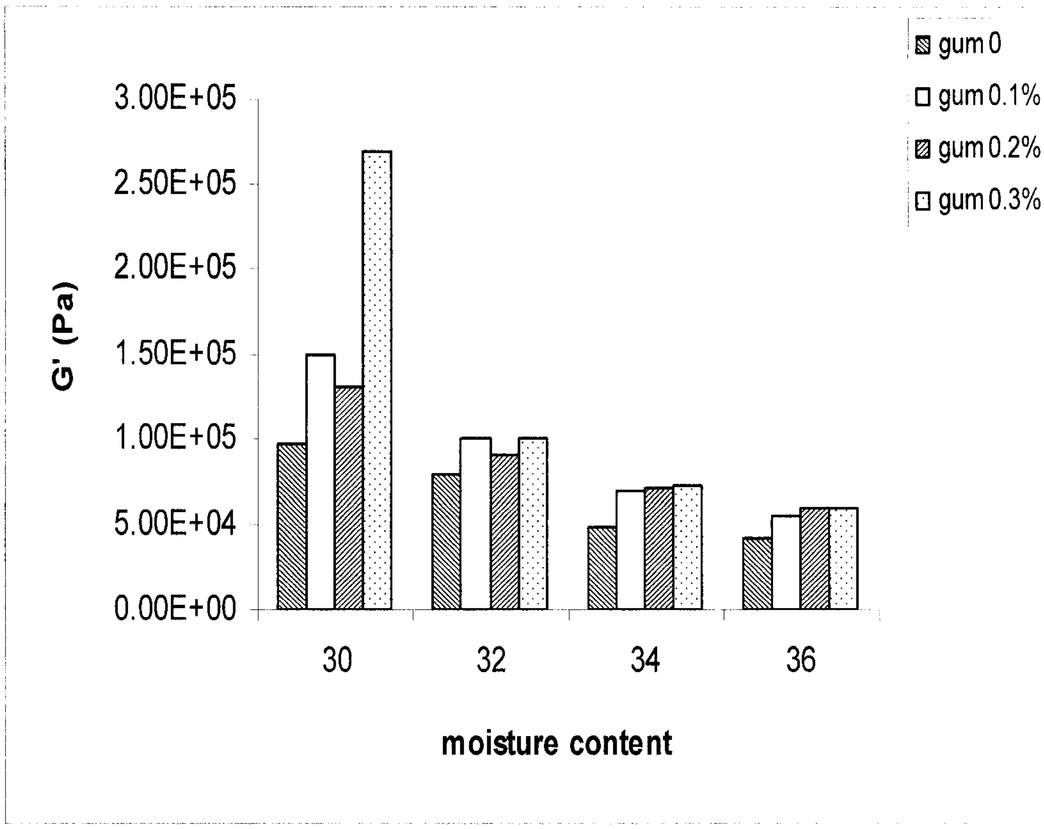

Fig. 3.5 Effect of moisture and gum on storage modulus for noodle dough

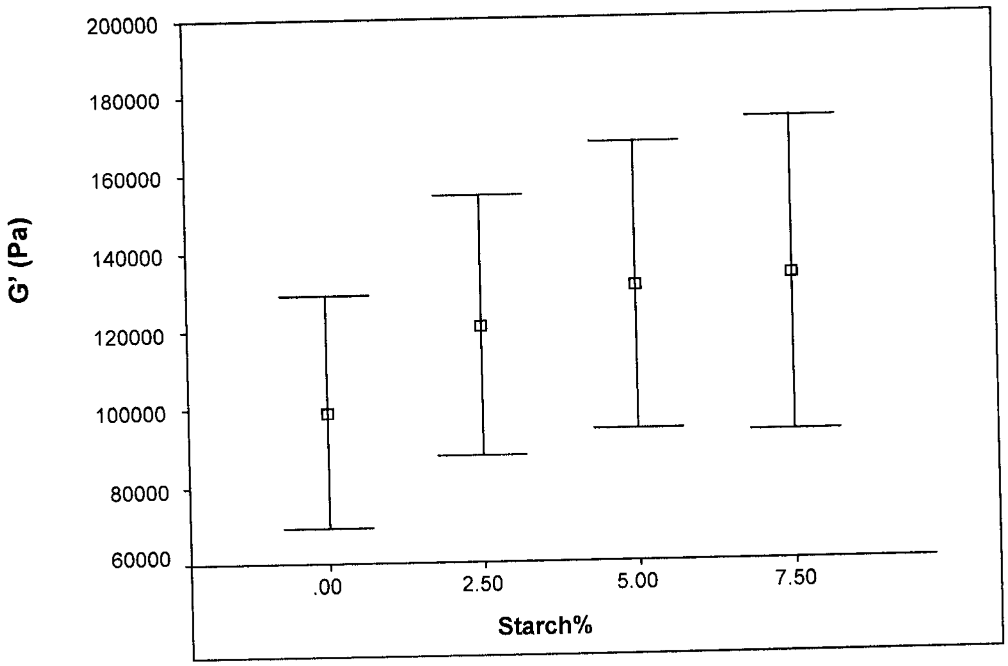

Fig. 3.6 Effect of starch on storage modulus for noodle dough (The range shown is 95% confidence interval)

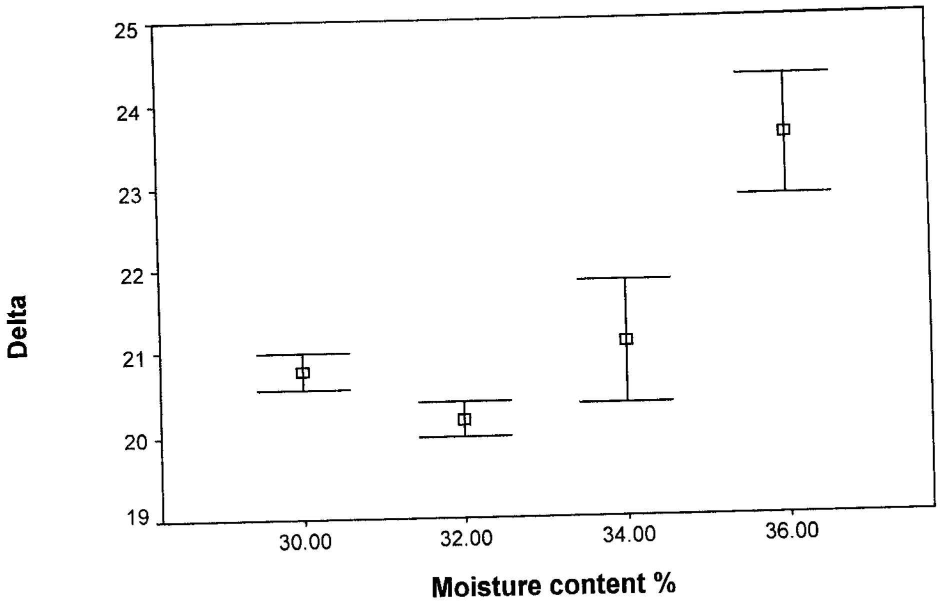

Fig. 3.7 Effect of moisture on phase angle for noodle dough (The range shown is 95% confidence interval)

Table 3.1: Ingredient effect on Young's modulus (E) for noodle dough by General Linear Model Analysis (GLM)

Dependent Variable: E

Source	dF	Sum of squares
Model	36	91.96
WATER	3	65.09*
STARCH	3	1.74
GUM	3	11.13*
WATER * STARCH	9	1.44
WATER * GUM	9	7.51*
STARCH * GUM	9	5.04
Error	27	8.04
Total	63	

* Significant at $p < 0.05$

Table 3.2: Ingredient effect on Energy at break point (EB) for noodle dough by General Linear Model Analysis (GLM)

Dependent Variable: E.B.

Source	df	Sum of Squares
Model	36	88.54
WATER	3	24.03*
STARCH	3	18.64*
GUM	3	2.43
WATER * STARCH	9	15.47*
WATER * GUM	9	12.09*
STARCH * GUM	9	15.85*
Error	27	11.46
Total	63	

* Significant at $p < 0.05$

Table 3.3: Ingredient effect on Storage modulus (G') for noodle dough by General Linear Model Analysis (GLM)

Dependent Variable: G'

Source	dF	Sum of Squares
Model	36	94.26
WATER	3	54.26*
STARCH	3	4.29*
GUM	3	22.04*
WATER * STARCH	9	3.24
WATER * GUM	9	8.64*
STARCH * GUM	9	1.79
Error	27	5.86
Total	63	

* Significant at $p < 0.05$

Table 3.4 Ingredient effect on Phase angle for noodle dough by General Linear Model Analysis (GLM)

Dependent Variable: DELTA

Source	dF	Sum of Squares
Model	36	86.13
WATER	3	63.75*
STARCH	3	1.68
GUM	3	3.45
WATER * STARCH	9	2.20
WATER * GUM	9	5.09
STARCH * GUM	9	9.96
Error	27	13.87
Total	63	

* Significant at $p < 0.05$

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CHAPTER 4: TEXTURAL AND OTHER QUALITY PROPERTIES OF INSTANT FRIED NOODLES AS AFFECTED BY SOME INGREDIENTS

4.1 CONNECTING STATEMENTS

In the previous chapter, the rheological properties of noodle dough were studied in relation to the ingredients. In this chapter, the textural and quality properties of instant fried noodles made by the noodle dough under similar conditions were studied. Textural properties and some cooking properties such as rehydration rate are important for determining the quality of instant noodles while fat absorption is an important factor that absorbs many nutritional concerns. The study in this chapter is to investigate the relationship between ingredients and the above quality factors in order to provide useful information for improving the quality of instant fried noodles.

The results of this study will be submitted for publication: *Li Juan Yu and Michael Ngadi. 2003. Textural and other quality properties of instant fried noodles as affected by some ingredients.*

4.2 ABSTRACT

The effects of certain noodle dough ingredients namely moisture, gum and starch on the textural and other quality characteristics of cooked instant noodles were studied. In all, three (3) ingredients, namely moisture content, gum content and starch were studied.

The results showed that both maximum load (ML) and strain at break point (SB) increased with increasing moisture content and starch addition level. Fat absorption decreased with increasing moisture content and starch addition level while the rehydration rate increased with increasing moisture content and starch addition from 0 to 6.0%, but gradually decreased at higher starch addition level from 6.0 to 9.2%. The effect of gum addition at 0.1, 0.2 and 0.3% was significant in all cases but reduced considerably or showed reverse effect at higher starch addition levels.

4.3 INTRODUCTION

Instant noodles which originated from the traditional Oriental noodle are popular today in the US market. This is partly due to the convenience of eating (short rehydration time) and partly due to their texture. Kubomura (1998) briefly expressed the texture of instant noodles as rubbery, firm, or smooth. Based on the research works by some pioneers, two general methods can be used for direct textural evaluation of noodles, namely sensory and instrumental. Some researchers also mentioned chemical method as a tool for indirect textural evaluation of noodles (Dexter 1985; D'Egidio et al. 1993). Sensory evaluation of noodle eating quality is a direct and ultimate method for evaluating the quality of final products. Nevertheless, sensory evaluation may be subjective, laborious and expensive. Therefore, quicker and more accurate methods suitable to evaluate the quality of noodles are required (Hou 2001).

Instrumental measurement of cooked noodle texture could be a reliable and convenient alternative evaluation to the sensory method (Oh et al. 1983; Lee et al. 1987; Hou et al. 1997). Two basic instrumental methods were commonly used. These are compression (including simple compression and Texture Profile Analysis (TPA) method) and tensile tests.

Oh (1983) gave the basis on how to perform cutting and compression on cooked noodles. He found that the maximum cutting stress and the resistance to compression of cooked dry noodles were highly correlated with noodle firmness and chewiness, respectively. Later on, several works were conducted using the above methods or modified methods based on them (Baik et al. 1994; Yun et al. 1997; Hou et al. 1997; Hatcher et al. 1999).

TPA method was first presented by Peleg (1976). Baik (1994) used TPA method to evaluate the starch and protein effects on noodles. He found that high starch pasting properties and swelling power may be responsible for high quality of Japanese noodles, but they may be less critical to the quality of Cantonese and instant noodles. Tensile test is also useful and commonly used in noodle study. Bhattacharya et al. (1999) and Srinivasan et al. (2000) used tensile test to determine the elasticity and extensibility of rice noodles and tortillas. Although these texture parameters are also important for instant noodles, much has not been reported about this development.

Most instant noodles are dried by deep frying. Since fat is a dietary requirement, nutritionists recommend that about 20 to 30% of daily calories come from fat. But unfortunately, all fats do not have the same nutritional quality. In Asia, most manufacturers use palm oil, a pleasant-tasting and highly saturated fat, which may cause certain coronary artery diseases. At present in North America, frying oil is typically composed of mixtures of canola, cottonseed and palm oils, but there is still health concern for the high level of oil absorption in fried instant noodles by consumers. But putting health concerns aside, most noodle lovers would still prefer a fried variety simply because oil makes foods rehydrated faster and taste better. So there is a need to find a balance between nutrition and mouth feel.

The objective of this study was to determine the influence of three ingredients namely moisture, starch and guar gum, on textural (tensile test) and other quality properties (fat absorption and rehydration) of instant fried noodles and to determine the relationship between these properties.

4.4 MATERIALS AND METHOD

4.4.1 Preparation of fried instant noodles

The preparation of instant noodle dough was according to 3.4.1 (materials and dough preparation).

The preparation of instant fried noodles was according to 4.4.1 (Preparation of fried instant noodles).

For making instant noodles, the dough sheet was further pressed through the noodle machine with the roller gap gradually reduced to 1.5 mm. Dough sheet was then cut through the cutter attachment. The dimension was 1.5 mm in width and 1.5 mm in thickness. The resulting noodle strip was placed uniformly into the steam pan. The steam pan was put into the preheated (100°C) steamer, and cooked for 2 min until the noodle strip was in smooth surface and had become elastic in texture. The next and final step is frying. A deep fat fryer (Computron 7000, Henny Penny Corp., Eaton, Ohio) and hydrogenated vegetable oil were used (Liquid Frying Shortening, CanAmera Foods®, Oakville, ON). The frying temperature was 150°C and the frying time was 2 min.

During frying the steamed noodle strips were separately placed in wire baskets throughout frying. The baskets were immersed to a depth of 10 cm in the frying oil. After frying, the noodle strips were allowed to cool and drain excess oil on the surface. The cooled samples were stored in plastic bags separately for further tests.

4.4.2 Fat analysis

The Soxhlet method was used for fat analysis (AOAC 1990). The fried noodles were ground uniformly using a homogenizer-blender (Proctor-Silex, model E160B, Picton, ON). Fat extraction was performed with petroleum ether, using a solvent extractor

(SER148, Velp Scientifica, Usmate, Italy). Measurement was carried out in three (3) repetitions and the average data collected was used for the analysis.

4.4.3 Noodle cooking

Six noodle strands (25 cm in length) were added to 400 ml boiling water in a 500ml beaker. The noodles were cooked to the optimum cooking time (4 min) according to the method of OH et al. (1983). After cooking, the noodles were cooled in a running tap water for 1 min. The drained noodles were then stored in a covered plastic container at room temperature (25°C) for 5 min before tensile test.

4.4.4 Tensile test

Tensile tests were conducted using the Instron Universal Testing Machine (Model 4201, powered by Instron Series IX software (Automated Materials Testing System, V.5)) with a two - grip attachment. Each end of the cooked noodle strip was wound three times around the grip. Friction held the noodle strip to the grip while tensile force was applied. A 0.5 kN load cell was used. The crosshead speed for all tests was 50 mm/min. All the tests were performed within 5 min. Several parameters were obtained, including maximum load, strain% at break point. All the tests were carried out in three repetitions and the average values were calculated and used for the statistical analysis.

4.4.5 Rehydration test

Noodle strands were cooked for 4 min until the white core disappeared. The cooked noodle strands were then placed in cold water, drained, wiped with paper towels and kept covered in plastic box. The gain in noodle weight after cooking was recorded as percentage rehydration according to the method by Beta and Corke (2001).

4.4.6 Experimental Design and Data analysis

Response Surface Methodology was used for analyzing the effect of variables (water, Gum and Starch) on quality properties (Maximum load, Strain at break, fat absorption, rehydration). The main advantage of it is the ability to decrease the experimental run required to provide sufficient information for statistically acceptable results. The second order response surface fitted to the data as an approximation to the true response surface. The experiments were processed in a random order and the data was analyzed using SPSS software (SPSS for Windows, release. 8.0.0. SPSS Inc. Chicago, IL). The general form of a quadratic polynomial model that was used in this study is illustrated by equation (1) for three X-variables.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 * X_2 + \beta_{13} X_1 * X_3 + \beta_{23} X_2 * X_3 \quad (4.1)$$

Where $\beta_1, \beta_2, \beta_3, \beta_{11}, \beta_{22}, \beta_{33}, \beta_{12}, \beta_{13}, \beta_{23}$ represent the estimated regression coefficients, with β_0 representing the intercept term, $\beta_1, \beta_2, \beta_3$ the linear effects, $\beta_{11}, \beta_{22}, \beta_{33}$ the quadratic effects and $\beta_{12}, \beta_{13}, \beta_{23}$ the interaction effects. While X_1, X_2, X_3 are the coded independent variables according to water addition, gum content and starch content respectively. Y represents the dependent variable (eg. maximum load, Strain at break, fat absorption, or rehydration rate) to be modeled (Kristo et al. 2003).

4.5 RESULTS AND DISCUSSION

4.5.1 Ingredient effect on textural properties of cooked instant noodles

4.5.1.1 Maximum load

Statistical analysis of data showed that moisture content and starch addition level significantly ($P < 0.05$) affected maximum load (ML) of cooked noodles as shown in Table 4.1. However, there was no significant effect of gum on maximum load (ML). This implies that both moisture content and starch affected the elasticity of cooked noodles.

The polynomial predictive model developed for the fitted response surface for the ingredient effect on maximum load can be expressed as:

$$ML = 0.8 + 0.07X_1 + 0.02X_1^2 + 0.06X_2 + 0.05X_2^2 + 0.09X_3 + 0.05X_3^2 - 0.01X_1X_3 - 0.01X_1 * X_2 - 0.04X_2 * X_3 \quad (4.2)$$

X_1 represents water addition, X_2 represents gum content and X_3 represents starch content. *ML* represents the dependent variable (maximum load).

From Figure 4.1, regression analysis showed that the maximum load increased steadily with increasing moisture content. The effect of gum addition at 0.1, 0.2 and 0.3% was also significant, particularly at 0.3% where the maximum load attained higher values for corresponding moisture content values. This indicated that the addition of gum significantly influenced the relationship between maximum load and moisture content of cooked instant noodles.

Regression analysis also indicated the effect of starch addition on maximum load as shown in Figure 4.2. The maximum load value increased with increasing starch addition level. The effect of gum addition at 0.1, 0.2 and 0.3% was also found to be significant, particularly at 0.3% which recorded the highest value of maximum load for corresponding moisture content value. However, the effect of gum addition diminished considerably at higher starch addition level, becoming almost negligible. This indicated that both starch and gums perform complimentary roles in enhancing the elasticity and textural quality of instant noodles.

4.5.1.2 Strain at break point

Statistical analysis of data showed that moisture content, gum content and starch addition level significantly ($P < 0.05$) affected strain at break point (SB) of cooked noodles as shown in Table 4.2.

The polynomial predictive model developed for the fitted response surface for the ingredient effect on strain at break point can be expressed as:

$$SB = 65.67 + 3.00X_1 + 2.88X_2 + 4.21X_3 + 2.55X_1^2 + 2.93X_2^2 + 1.66X_3^2 + 0.55X_1 * X_2 - 1.52X_2 * X_3 + 1.10X_1 * X_3 \tag{4.3}$$

X_1 represents water content, X_2 represents gum content and X_3 represents the amount of starch added. *SB* represents the dependent variable (Strain at break point).

From Figure 4.3, regression analysis showed that the strain at break point (SB) increased steadily with increasing moisture content in the range from about 30 to 40%. The effect of gum addition at 0.1, 0.2 and 0.3% was also significant, particularly at 0.3% where strain at break point attained highest values for corresponding moisture content values. This indicated that the addition of gum in varying quantities significantly influence the relationship between strain at break point and moisture content of cooked instant noodles.

Regression analysis also indicated the effect of starch addition on strain at break point (SB) as shown in Figure 4.4. The strain at break increased with the increasing starch addition level from 0 to 9.2%. The effect of gum addition at 0.1, 0.2 and 0.3% was also found to be significant particularly at 0.3% which recorded the highest value of the strain at break for corresponding starch addition level. However, the effect of gum addition reduced considerably at 9.2% starch addition, becoming very small. Again indicated that both starch and gum perform complimentary roles in enhancing the extensibility and textural quality of instant noodles.

4.5.2 Ingredient effect on fat absorption of instant noodles

Statistical analysis of data showed that starch addition level significantly ($P < 0.05$) affected fat absorption level of instant noodles as shown in Table 4.3. The interaction of gum and starch was also significant ($P < 0.05$). This indicated that there might be some cross-link occurrence between starch and gum during starch gelatinization process which led to an indirect effect of gum on the fat absorption level of instant noodles.

The polynomial predictive model developed for the fitted response surface for the ingredient effect on fat absorption level can be expressed as:

$$\begin{aligned} FAN &= 22.37 + 0.23X_1 - 0.48X_2 - 0.70X_3 + 0.37X_1^2 - 0.05X_2^2 \\ &+ 0.35X_1 * X_2 + 0.70X_2 * X_3 + 0.08X_1 * X_3 \end{aligned} \tag{4.4}$$

X_1 represents water content, X_2 represents gum content and X_3 represents the amount of starch added. *FAN* represents the dependent variable (Fat absorption).

From Figure 4.5, regression analysis showed that fat absorption decreased with increasing moisture content from about 30 to 35%. Fat absorption later increased as the moisture content was increased from 35 to 40%. The effect of gum addition at 0.1, 0.2 and 0.3% was also significant particularly at 0.3% which recorded the lowest value for the fat absorption for corresponding moisture content. At the initial increase in moisture content from 30 to 35%, gum addition from 0.1 to 0.3% decreased the fat absorption. However, as the moisture content was increased from 35 to 40%, the effect of gum addition became less significant, almost terminating at 40% moisture content. This indicated that gum, as a hydrocolloid substance adversely affected the functionality of moisture content at the initial stage, thereby reducing fat absorption. But as moisture content was increased, the effect of gum became less pronounced while the fat absorption steadily increased.

Regression analysis also indicated that fat absorption decreased steadily with increasing starch addition as shown in Figure 4.6. The effect of gum addition showed reversed effect when the starch addition was greater than 6.8%. This indicated that gum content when combined with higher starch addition level showed a tendency to increase fat absorption in instant noodles.

4.5.3 Ingredient effect on rehydration of instant noodles

Statistical analysis of data showed that moisture content, gum content and starch addition level significantly ($P < 0.05$) affected rehydration rate of instant noodles as shown in Table 4.4. However, there was no interaction effect within the test limit.

The polynomial predictive model developed for the fitted response surface for the ingredient effect on rehydration rate can be expressed as:

$$RT = 1.45 + 0.05X_1 + 0.03X_2 + 0.02X_3 + 0.01X_1 * X_3 + 0.02X_2^2 - 0.02X_3^2 \qquad (4.5)$$

X_1 represents water content, X_2 represents gum content and X_3 represents the amount of starch added. *RT* represents the dependent variable (rehydration rate). As shown in Figure 4.7, the regression analysis indicated that rehydration rate increased linearly as the moisture content was increased. Addition of gum at 0.1, 0.2 and 0.3% also showed a significant effect. The highest rehydration rate was observed at 0.3% gum addition for corresponding moisture content values. This indicated that gum addition in the presence of moisture content generally supports the rate of rehydration of cooked instant noodles.

From Figure 4.8, the regression analysis also indicated that the rehydration rate increased steadily with increasing starch addition level from 0 to 6.0%. However, at higher starch addition levels from 6.0 to 9.2%, the rehydration rate gradually decreased. The effect of gum addition at 0.1, 0.2 and 0.3% was also found to be significant particularly at 0.3% which recorded the highest values of the rehydration rate at corresponding starch addition levels.

4.6 CONCLUSION

From the proceeding discussions and analysis of results, it could be observed that ingredients of noodle dough such as moisture content, gum content and starch addition generally influenced the characteristics of instant noodles.

The addition of gum in varying quantities was found to play a significant role in the relationships between maximum load, strain at break point and moisture content for instant noodles. It was also observed that both starch and gum performed complimentary roles in enhancing the elasticity and extensibility of instant fried noodles.

Moreover, it was observed that while gum as an hydrocolloid substance in water reduced fat absorption at low moisture content, it generally increased the rate of rehydration of instant noodles. Also, starch addition lower than 6.8% in the presence of gum steadily decreased fat absorption. While starch addition lower than 6.0% in the presence of gum increased rehydration rate of instant noodles.

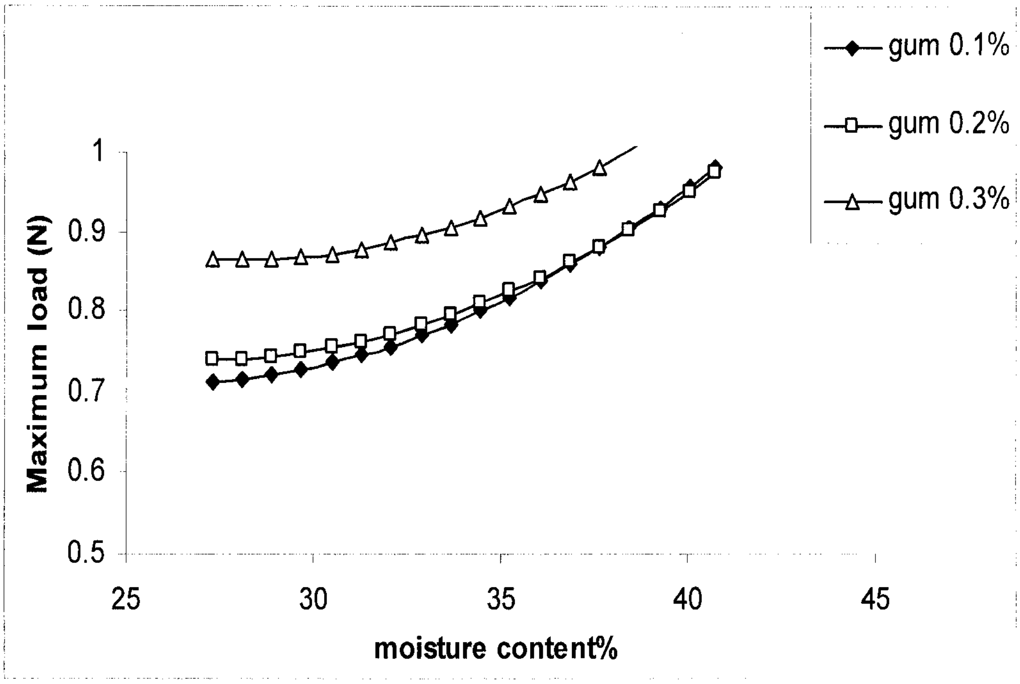

Fig. 4.1 Moisture effect on maximum load for cooked instant noodles

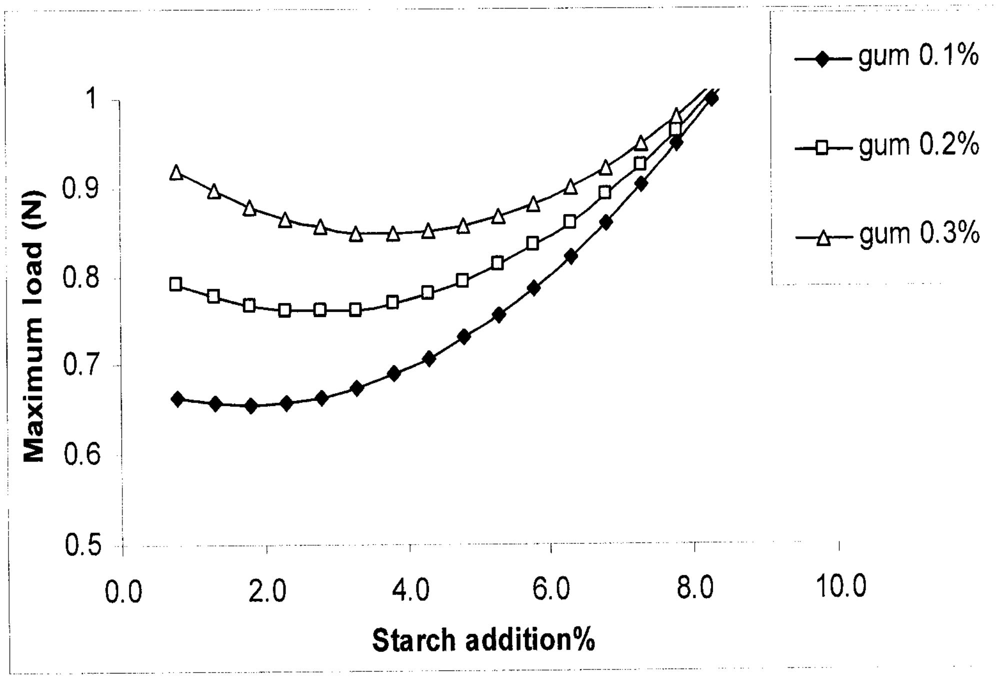

Fig. 4.2 Starch addition effect on maximum load for cooked instant noodles

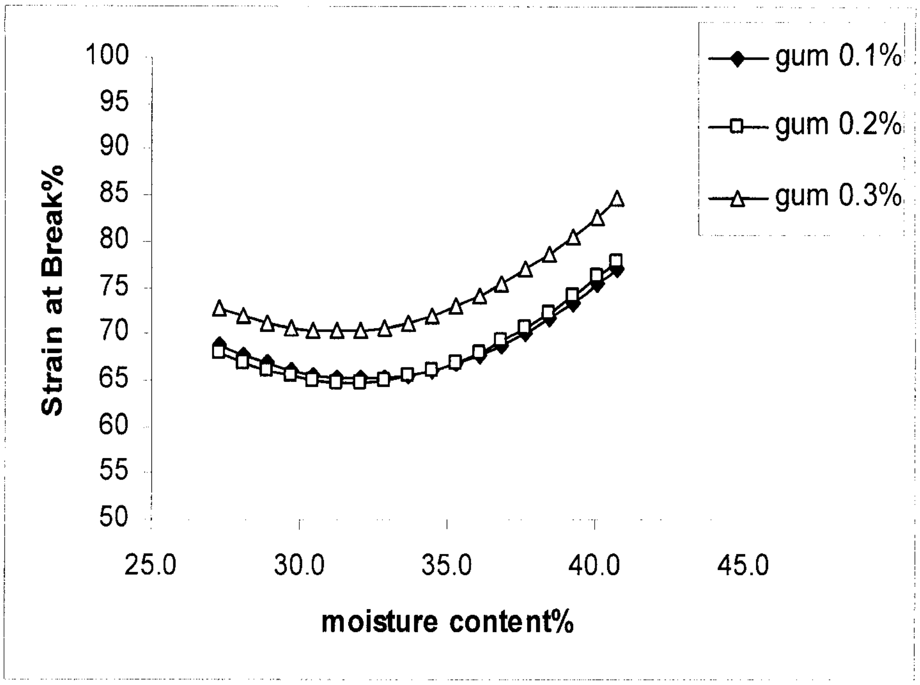

Fig. 4.3 Moisture effect on strain at break for cooked instant noodles

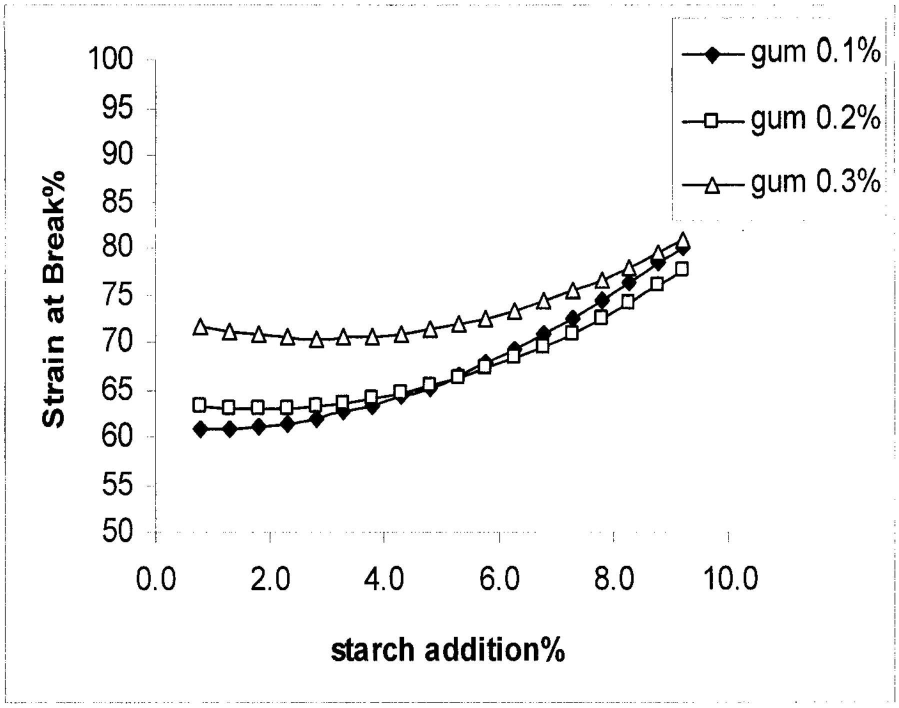

Fig. 4.4 Starch effect on strain at break for cooked instant noodles

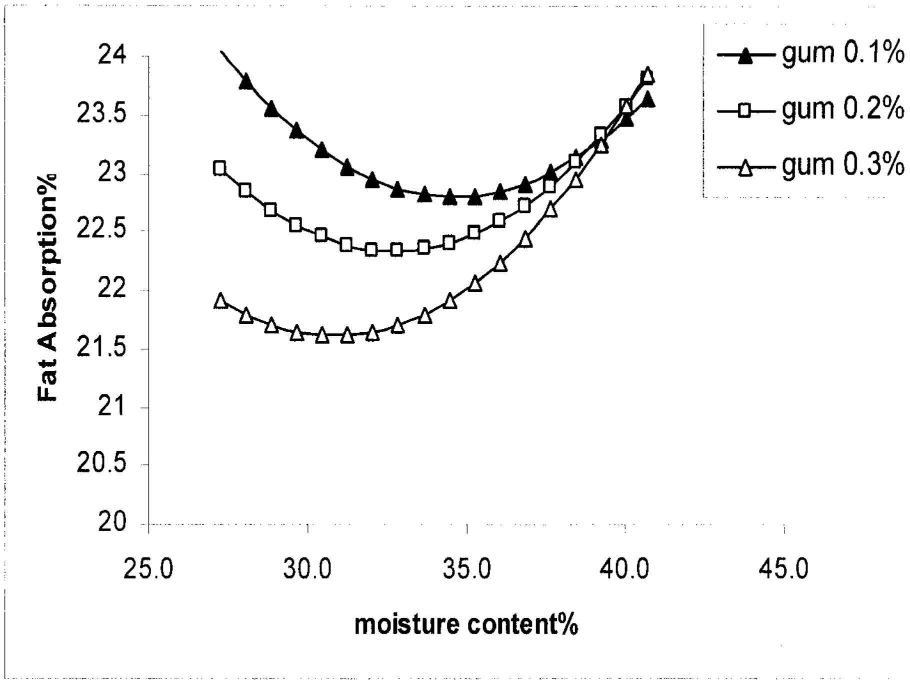

Fig. 4.5 Moisture effect on fat absorption for instant noodles

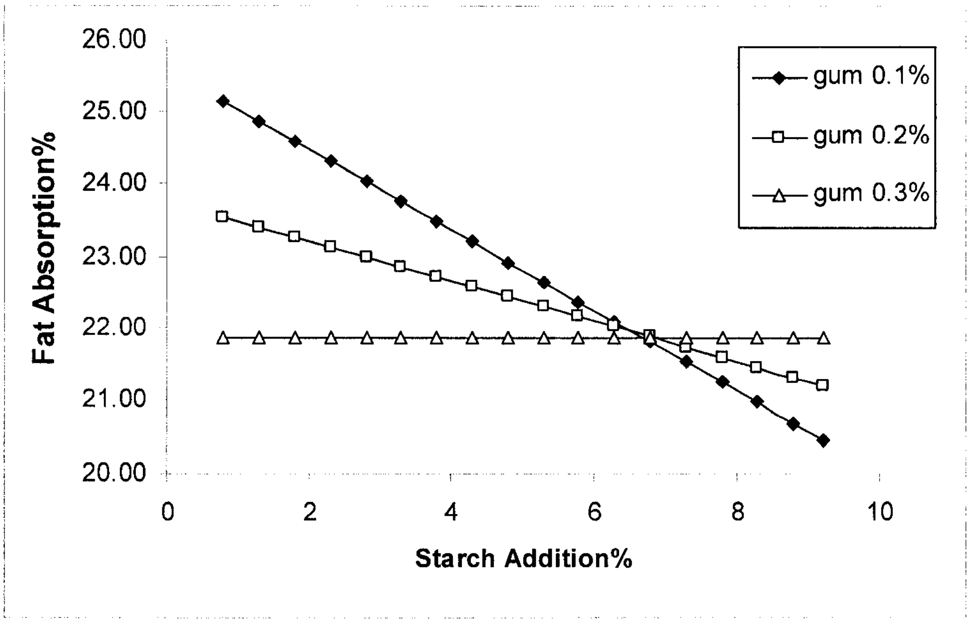

Fig. 4.6 Starch addition effect on fat absorption for instant noodles

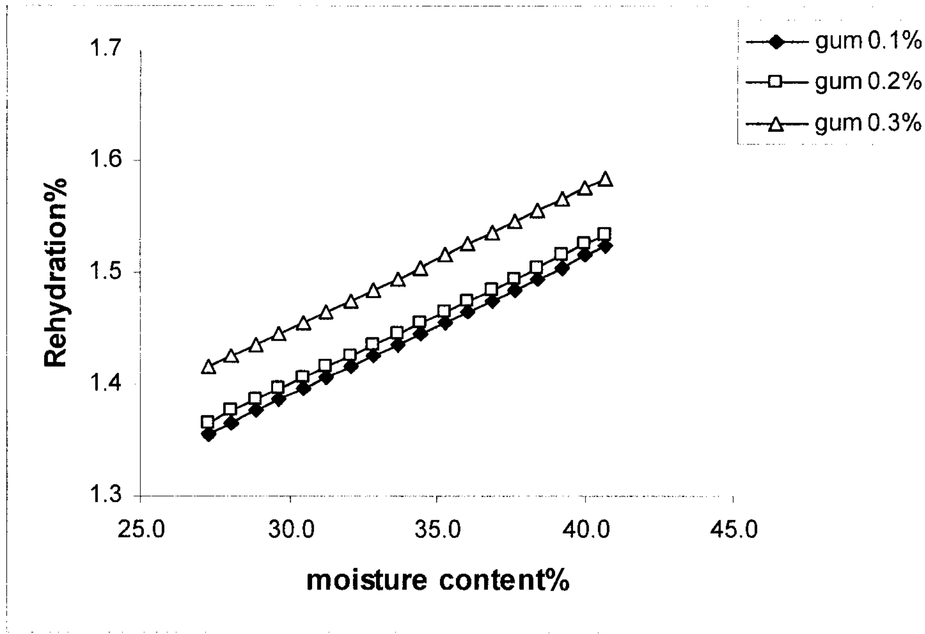

Fig. 4.7 Moisture effect on rehydration rate for cooked instant noodles

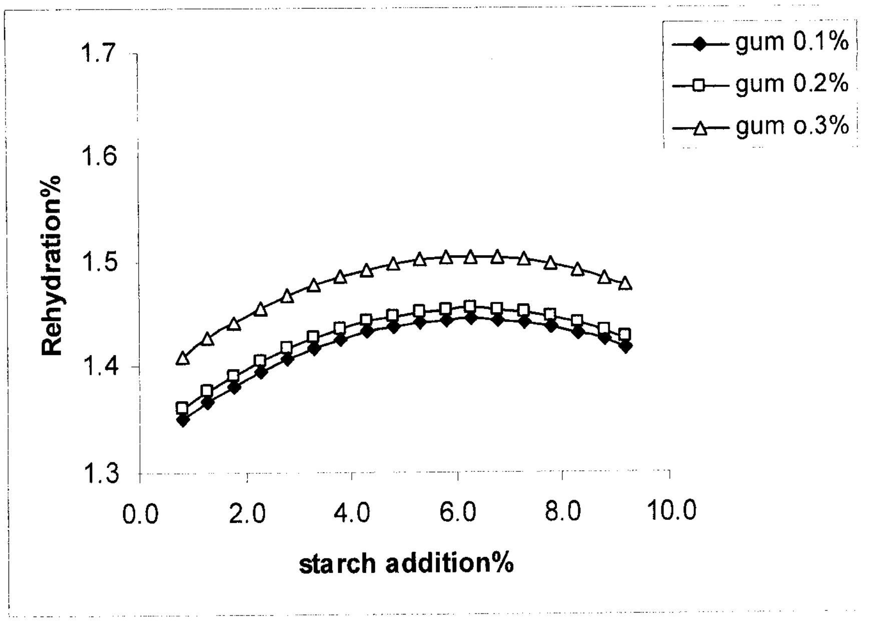

Fig. 4.8 Starch addition effect on rehydration rate for cooked instant noodles

Table 4.1: Ingredient effect on Maximum load (ML) for cooked instant noodles by General Linear Model Analysis (GLM)

Source	Type III Sum of Squares	Mean Square	F	Sig.
Model	0.371	0.029	4.148	0.045
WATER	0.130	0.043	6.303	0.028*
GUM	0.090	0.030	4.364	0.059*
STARCH	0.140	0.047	6.788	0.023*
WATER * GUM	0.001	0.001	0.182	0.685
WATER * STARCH	0.001	0.001	0.182	0.685
GUM * STARCH	0.011	0.011	1.636	0.248
Error	0.041	0.007		
Total	0.412			

* Significant at $p < 0.05$

Table 4.2: Ingredient effect on Strain at break (SB) for cooked instant noodles by General Linear Model Analysis (GLM)

Source	Type III Sum of Squares	Mean Square	F	Sig.
Model	770.040	59.234	5.345	0.025
WATER	207.075	69.025	6.228	0.028*
GUM	232.999	77.666	7.008	0.022*
STARCH	311.924	103.975	9.382	0.011*
WATER * GUM	2.409	2.409	0.217	0.657
WATER * STARCH	9.658	9.658	0.871	0.387
GUM * STARCH	18.575	18.575	1.676	0.243
Error	66.494	11.082		
Total	836.534			

* Significant at $p < 0.05$

Table 4.3: Ingredient effect on fat absorption for instant noodles by General Linear Model Analysis (GLM)

Source	Type III Sum Squares	Mean Square	F	Sig.
Model	19.476	1.498	4.981	0.030
WATER	3.978	1.326	4.408	0.058
GUM	3.374	1.125	3.739	0.080
STARCH	6.813	2.271	7.549	0.018*
WATER * GUM	0.959	0.959	3.189	0.124
WATER * STARCH	0.050	0.050	0.165	0.699
GUM * STARCH	3.962	3.962	13.172	0.011*
Error	1.805	0.301		
Total	21.281			

* Significant at $p < 0.05$

Table 4.4: Ingredient effect on rehydration rate for cooked instant noodles by General Linear Model Analysis (GLM)

Source	Type III Sum Squares	Mean Square	F	Sig.
Model	0.08065	0.00620	8.963	0.007
WATER	0.04732	0.01577	22.790	0.001*
GUM	0.01708	0.00569	8.226	0.015*
STARCH	0.01111	0.00370	5.349	0.039*
WATER * GUM	0.00036	0.00036	0.527	0.495
WATER * STARCH	0.00097	0.00097	1.399	0.282
GUM * STARCH	0.00036	0.00036	0.527	0.495
Error	0.00415	0.00069		
Total	0.08480			

* Significant at $p < 0.05$

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CHAPTER 5: CORRELATION BETWEEN DOUGH RHEOLOGY AND QUALITIES OF INSTANT FRIED NOODLES

5.1 CONNECTING STATEMENTS

In the previous study, the rheological properties of noodle dough and quality characteristics of instant noodles were investigated. The study in this chapter is to investigate the correlation between dough rheology and qualities of instant noodles and provide useful information for quality control and prediction of instant noodles.

The results of this study will be submitted for publication: *Li Juan Yu and Michael Ngadi. 2003. Correlation between dough rheology and qualities of instant noodles.*

5.2 ABSTRACT

Certain correlations that are essentially important to the food industry have been found to exist between rheology and qualities of instant noodles. In this study, some of these correlations were identified. The results indicated that most rheological parameters of noodle dough showed correlations to the characteristics of instant noodles.

Positive correlations were found between the energy at break (EB) for noodle dough, maximum load (ML) and strain at break (SB) for cooked instant noodles. Positive correlation was also found between the phase angle (δ) for noodle dough and the strain at break (SB). However, negative correlations were found between Young's modulus (E) for noodle dough and maximum load as well as strain at break for cooked instant noodles. This indicated that rheological parameters of noodle dough could be useful in predicting the quality characteristics of the final instant noodles.

A substantial correlation was also found within the dynamic rheological properties such as storage modulus (G') and phase angle (δ) as well as fundamental rheological properties like Young' modulus and energy at break for noodle dough. Considerable correlations were also found within the quality characteristics of instant noodles namely strain at break, maximum load, rehydration rate and fat absorption.

5.3 INTRODUCTION

Instant noodles are popular worldwide. Apart from their relatively low price, they have a desirable texture that matches consumer preference and they are easy to produce. These attributes are partly due to the frying process used in their manufacture. Frying not only creates a higher rehydration rate, but it also delivers a delicious taste to the final product which is the instant noodles. However, high oil content of instant noodles still causes some health concerns among nutritionists and consumers (Melton 1996). Kim (1996) reported that instant noodles generally refer to steamed and deep fat fried products, which are called "ramyon" in Korea and "ramen" in Japan. He further stated that instant noodles were introduced in Japan in 1958 and in Korea in 1963; and the actual process for instant noodle manufacture may differ from company to company and from country to country but the basic principles involved in the manufacture are practically the same. Kim (1996) also defined quality in terms of conformity and requirement. He however opinioned that the criteria for assessing noodle quality are not well established. But certain factors could be considered in evaluating instant noodle quality such as flour quality, processing conditions, eating quality and keeping quality.

According to Hibberd and parker (1975), materials can be classified rheologically according to their behavior which in simplest form may either be ideal elastic solid (Hookean) or perfect viscous liquid (Newtonian). But most materials do not behave in either of these two ideal ways. Such materials are said to be viscoelastic and the dough is a clear example of this. There are two types of viscoelastic behaviors often described as linear and non-linear. The dough is classified as a non-linear viscoelastic material.

Viscoelasticity is a rheological behavior of materials which has been found to play a substantial role in the study of dough rheology which is generally characterized by both fundamental and dynamic properties.

Many rheological methods have been used to predict the qualities of cereal food products. The relationship between fundamental and dynamic rheological properties of dough and qualities of noodles and breads had also been investigated by many researchers. Autio (2001) investigated the correlation between the rheological measurements and baking performance of bread. He found that all the rheological properties of dough correlated with bread weight. Oh et al (1983) also reported that the maximum cutting stress and resistance to compression for cooked dry noodles were highly correlated to raw noodle textural characteristics like firmness and chewiness. Furthermore, Yeh et al. (1999) and Shiau et al. (2001) studied the effects of oxido-reductants and Alkali-acids on rheological properties of wheat flour dough. They compared the correlation between the rheological properties of wheat dough with texture and cooking properties of extruded noodles. The result showed that the dough rheology significantly correlated to the quality characteristics of extruded noodles at low temperatures.

The objective of this study was to investigate the correlations between dough rheological properties and qualities of instant noodles with particular emphasis on textural properties, rehydration rate and fat absorption.

5.4 MATERIALS AND METHOD

5.4.1 Preparation of noodle dough and instant fried noodles

The preparation of instant noodle dough was according to 3.4.1.

The preparation of fried instant noodles was according to 4.4.1.

5.4.2 Fundamental test of noodle dough

The procedure of fundamental test on noodle dough was according to 3.4.2.

5.4.3 Dynamic test of noodle dough

The procedure of dynamic test on noodle dough was according to 3.4.3.

5.4.4 Fat analysis of instant noodles

The procedure of fat analysis on instant noodles was according to 4.4.2.

5.4.5 Tensile test of cooked instant noodles

The procedule of tensile test on cooked instant noodles was according to 4.4.4.

5.4.6 Rehydration test of cooked instant noodles

The procedule of rehydration test on cooked instant noodles was according to 4.4.5.

5.4.7 Statistical analysis

Response Surface Methodology was used for analyzing the effect of variables (water, Gum and Starch) on both rheological properties of noodle dough and quality properties (Maximum load, Strain at break, fat absorption, rehydration). The main advantage of it is the ability to decrease the experimental run required to provide sufficient information for statistically acceptable results. The second order response surface fitted to the data as an approximation to the true response surface. The experiments were processed in a random order and the data were analyzed using SPSS software (SPSS for Windows, release. 8.0.0. SPSS Inc. Chicago, IL). The general form of a quadratic polynomial model that was used in this study is illustrated by this equation for three X-variables.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 * X_2 + \beta_{13} X_1 * X_3 + \beta_{23} X_2 * X_3 \quad (5.1)$$

Where $\beta_1, \beta_2, \beta_3, \beta_{11}, \beta_{22}, \beta_{33}, \beta_{12}, \beta_{13}, \beta_{23}$ represent the estimated regression coefficients, with β_0 representing the intercept term, $\beta_1, \beta_2, \beta_3$ the linear effects, $\beta_{11}, \beta_{22}, \beta_{33}$ the quadratic effects and $\beta_{12}, \beta_{13}, \beta_{23}$ the interaction effects. While X_1, X_2, X_3 are the coded independent variables according to water addition, gum content and starch content respectively. Y represents the dependent variable (eg. maximum load, Strain at break, fat absorption, or rehydration rate) to be modeled (Kristo et al. 2003).

Bi-variate correlation procedure of SPSS was also used for the correlation analysis. The data were provided by the regression analysis.

5.5 RESULT AND DISCUSSION

5.5.1 Correlation between dynamic and fundamental rheological parameters of noodle dough

The fitted response surface equations for rheological parameters are as follows:

$$G' = 190238.41 - 54031.79X_1 + 43986.94X_2 + 8157.65X_3 + 3391.71X_1^2 - 5447.12X_2^2 + 10639.57X_3^2 + 14125X_1 * X_2 - 9125X_1 * X_3 + 4125X_2 * X_3 \quad (5.2)$$

G' represents the storage modulus of noodle dough; X_1, X_2 and X_3 represent moisture content, gum content and starch addition level respectively.

$$\delta = 20.15 + 0.48X_1 - 0.05X_2 - 0.18X_3 + 0.43X_1^2 + 0.03X_2^2 + 0.21X_1 * X_2 + 0.16X_1 * X_3 + 0.26X_2 * X_3 \quad (5.3)$$

δ represents the phase angle of noodle dough; X_1, X_2 and X_3 represent moisture content, gum content and starch addition level, respectively.

$$E = 139.37 - 38.16X_1 + 19.72X_2 - 0.51X_3 - 11.66X_1^2 - 8.45X_2^2 + 1.87X_3^2 - 7.81X_1 * X_2 - 2.29X_1 * X_3 + 3.51X_2 * X_3 \quad (5.4)$$

E represents the Young' modulus of noodle dough; X_1, X_2 and X_3 represent moisture content, gum content and starch addition level respectively.

$$EB = 4.56 + 1.54X_1 + 0.14X_2 - 0.47X_3 + 1.75X_1^2 + 0.92X_2^2 + 1.06X_3^2 - 0.90X_1 * X_2 - 0.72X_1 * X_3 - 1.67X_2 * X_3 \quad (5.5)$$

EB represents the energy at break of noodle dough; X_1, X_2 and X_3 represent moisture content, gum content and starch addition level respectively.

The correlation coefficients of dynamic and fundamental rheological parameters of noodle dough are presented in Table 5.1. Correlation was found between all dynamic rheological parameters such as storage modulus (G') and phase angle (δ) and fundamental rheological parameters such as Young' modulus (E) and energy at break (EB). The correlation between storage modulus (G') and Young' modulus (E) was the highest; and the correlation between phase angle (δ) and energy at break (EB) was the lowest, others were between them.

Storage modulus (G') showed positive relationship with Young' modulus (E) because both of them reflected the elastic nature of noodle dough. Energy at break (EB) was positively correlated with phase angle, and negatively correlated with Young's modulus (E) and storage modulus (G'). This indicated that the increase in the energy at break was largely contributed to by the liquid or viscous nature of noodle dough in the experimental range. Moreover, phase angle was negatively correlated to Young' modulus (E) and storage modulus (G') and positively correlated to energy at break which further confirmed the conclusion that the increase in phase angle (δ) and energy at break reflected the increase in viscous properties of noodle dough in the experimental range.

5.5.2 Correlation between rheological properties of dough and properties of instant noodles

The fitted response surface equations for textural and other quality parameters of instant noodles are as follows:

$$ML = 0.8 + 0.07X_1 + 0.02X_1^2 + 0.06X_2 + 0.05X_2^2 + 0.09X_3 + 0.05X_3^2 - 0.01X_1X_3 - 0.01X_1 * X_2 - 0.04X_2 * X_3 \quad (5.6)$$

$$SB = 65.67 + 3.00X_1 + 2.88X_2 + 4.21X_3 + 2.55X_1^2 + 2.93X_2^2 + 1.66X_3^2 + 0.55X_1 * X_2 - 1.52X_2 * X_3 + 1.10X_1 * X_3 \quad (5.7)$$

$$FAN = 22.37 + 0.23X_1 - 0.48X_2 - 0.70X_3 + 0.37X_1^2 - 0.05X_2^2 + 0.35X_1 * X_2 + 0.70X_2 * X_3 + 0.08X_1 * X_3 \quad (5.8)$$

$$RT = 1.45 + 0.05X_1 + 0.03X_2 + 0.02X_3 + 0.01X_1 * X_3 + 0.02X_2^2 - 0.02X_3^2 \quad (5.9)$$

The correlation coefficients between rheological parameters of noodle dough and fat absorption of instant noodles are presented in Table 5.2. Correlation was found between all rheological parameters and fat absorption for instant noodles. The highest correlation was found between oil absorption and phase angle (δ). This result indicated that fat absorption could best be predicted by phase angle within the experimental range. Phase angle was positively correlated to the oil absorption level which suggested that a possible way to reduce fat absorption was to reduce moisture content in noodle dough.

The correlation coefficients between dynamic and fundamental rheological parameters of noodle dough and rehydration rate of instant noodles are presented in Table 5.3. Correlation was found between all dynamic and fundamental parameters with rehydration rate. With increased Young's modulus (E) and storage modulus (G'), the rehydration rate decreased. And With increased phase angle (δ) and energy at break (EB), the rehydration rate increased. This result indicated that the rehydration rate could be predicted by either Young's modulus (E), storage modulus (G'), phase angle (δ) or energy at break (EB) within the experimental range.

The correlation coefficients between dynamic and fundamental rheological parameters of noodle dough and textural parameters of cooked noodles are presented in Table 5.4 a. and b. Good positive correlation was found between Energy at break (EB) for noodle dough and maximum load and strain at break point for cooked noodles. Also positive correlation between phase angle and strain at break was found, but smaller than the above result. Negative correlation was found between Young's modulus (E) for noodle dough, maximum load and strain at break point for cooked noodles. Strain at break indicated the extensibility of cooked noodles and maximum load represented the elasticity for cooked noodles (Bhattacharya 1999). The above result indicated that both the extensibility and elasticity had close relationship with energy at break (EB).

5.5.3 Correlation between the characteristics of instant noodles

The correlation coefficients between textural parameters and fat absorption, rehydration rate for cooked noodles are presented in Table 5.5. Good positive correlation was found between strain at break, maximum load and rehydration rate. And also positive correlation was found between maximum load and rehydration rate. Negative correlation was got between fat absorption, strain at break and maximum load. No correlation was found between fat absorption and rehydration rate.

5.6 CONCLUSION

From the proceeding discussions and analysis of results, it could be observed that most rheological parameters of noodle dough showed correlation to the characteristics of instant noodles. Positive correlation was found between Energy at break (EB) for noodle dough, maximum load and strain at break point for cooked noodles. Also, positive correlation was found between phase angle and strain at break, but smaller than the above result. However, a negative correlation was found between Young's modulus (E) for noodle dough, maximum load and strain at break point for cooked noodles. This indicated that these rheological parameters of noodle dough have the ability of predicting the quality characteristics of the final instant noodles. There was also a considerable correlation between all dynamic rheological parameters such as storage modulus (G') and phase angle (δ) and fundamental rheological parameters such as Young's modulus (E) and energy at break (EB) of noodle dough. Furthermore, a meaningful correlation was found between all the quality characteristics of instant noodles namely strain at break, maximum load, rehydration rate and fat absorption.

Table 5.1 Correlation coefficients (γ) between dynamic and fundamental rheological parameters of noodle dough

	δ	G'	E	EB
δ	1	-0.418*	-0.688*	0.237*
G'		1	0.825*	-0.414*
E			1	-0.467*
EB				1

* Correlation is significant at the 0.05 level

Table 5.2 Correlation coefficients of fat absorption for instant noodles with rheological parameters of noodle dough

Rheological parameters vs. Fat absorption	γ
δ	0.746*
G'	-0.270*
E	-0.348*
Energy at break	0.220*

* Correlation is significant at the 0.05 level

Table 5.3 Correlation coefficients of rehydration rate for cooked instant noodles with rheological parameters of noodle dough

Rheological parameters vs. Rehydration rate	γ
δ	0.406*
G'	-0.322*
E	-0.488*
Energy at break	0.328*

* Correlation is significant at the 0.05 level

Table 5.4 a: Correlation coefficients of textural parameters (Maximum load) for cooked instant noodles with rheological parameters of noodle dough

Rheological parameters vs. Maximum load	γ
δ	0.009
G'	-0.041
E	-0.288*
Energy at break	0.518*

* Correlation is significant at the 0.05 level

Table5.4 b: Correlation coefficients of textural parameters (Strain at break) for cooked instant noodles with rheological parameters of noodle dough

Rheological parameters vs. Strain at break.	γ
δ	0.229*
G'	-0.010
E	-0.350*
Energy at break	0.546*

* Correlation is significant at the 0.05 level

Table 5.5: Correlation coefficients of textural parameters with fat absorption and rehydration rate of instant noodles

	Fat absorption	Rehydration	Max. load	Strain at break
Fat absorption	1	-0.179	-0.579*	-0.414*
Rehydration		1	0.664*	0.708*
Max. load			1	0.922*
Strain at break				1

* Correlation is significant at the 0.05 level

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CHAPTER 6: GENERAL CONCLUSIONS

From the proceeding discussions and analysis of results, as shown in Chapter 3 and 4, it could be observed that ingredients such as moisture content, gum content and starch addition level play important roles in the rheology of noodle dough as well as the quality characteristics of instant noodles. Also Chapter 5 focused on the correlation of rheological properties of noodle dough and quality properties of instant noodles. The discussions pertaining to these observations could be discussed as follows:

Moisture content was found to be an important factor that governs the rheological properties of noodle dough. With the increase in moisture content, the Young's modulus (E), energy at break (EB) and storage modulus (G') decreased, and the phase angle (δ) increased. Gum was also a determinant in the rheological properties of noodle dough. This could be observed from Young's modulus (E), energy at break (EB) and storage modulus (G') which increased with the increase in gum content. Starch effect was less significant compared to gum and moisture. Moreover, interaction effects between water, gum and starch on some rheological parameters were also observed.

Moisture content and starch addition level positively affected the textural properties, maximum load (ML) and strain at break for cooked noodles separately. However, there was no significant effect of gum on Maximum load (ML) for cooked noodles. Starch addition alone and the interaction of gum and starch show negative effect on fat absorption. While starch addition level, gum and moisture content give positive effects on rehydration rate for final noodles.

Most rheological parameters of noodle dough showed correlation to the characteristics of instant noodles. Positive correlation was found between Energy at break

(EB) for noodle dough, maximum load and strain at break point for cooked noodles. Also, positive correlation between phase angle for noodle dough and strain at break for cooked noodles was found, but smaller than the above result. Negative correlation was however found between Young's modulus (E) for noodle dough, maximum load and strain at break point for cooked noodles.

From the above discussions, it could be concluded that the effects of certain ingredients water, gum and starch play very important roles in the determination of the rheological properties of noodle dough as well as the textural and quality characteristics of instant noodles. It could also be concluded that the rheological parameters of noodle dough have the ability to predict the characteristics of the final instant noodles as evident from the analysis of results and discussion.

RECOMMENDATIONS

A review of literature showed that several studies have been conducted on the rheological properties of dough and qualities of some noodles. However, limited work was found on the rheological and quality properties of instant fried noodles.

As demonstrated throughout this study, ingredients effects on the rheological properties of dough and qualities of instant noodles were found. Further studies on the influence of processing factors such as temperature, time on these properties need to be conducted.

Results from the correlation between rheological properties of dough and quality properties of instant noodles were also analysed. From the analysis conducted it is recommended that further studies be carried out on the prediction models of this work.