EFFECTS OF FIBER CONTENT AND EXTRUSION CONDITIONS ON QUALITY OF PASTA

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ABSTRACT

EFFECTS OF FIBER CONTENT AND EXTRUSION CONDITIONS ON QUALITY OF PASTA

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Both characteristics of raw material and processing conditions play an important role in the final quality of pasta. Durum wheat semolina is the main ingredient for pasta production due to its yellow-amber color and strong gluten proteins. Pasta can be enriched with other cereals, pseudo-cereals, whole wheat flours or pure fibers to enhance the product nutritionally. However, partial substitution of durum wheat flour with these raw materials has an adverse effect on product quality. The aim of this study was to investigate the effects of the addition of 5% lemon fiber and extrusion conditions on quality of pasta. Samples were produced at two temperature sets in the extruder: 40 ºC, 40 ºC, 65 ºC, 45 ºC (die:55 ºC) which was called as low temperature (LT) and 65 ºC, 65 ºC, 85 ºC, 70 ºC (die:80 ºC) which was called as high temperature (HT). In this study, it was observed that both addition of lemon fiber and extrusion temperatures did not affect the cooking time, cooking loss and texture of products. A higher swelling index was observed when the extrusion temperature increased. Lemon fiber addition had no effect on swelling index at low temperature but it increased swelling index at high temperature. The water absorption index increased as extrusion temperature increased and with the addition of lemon fiber. It was observed that the rehydration rate increased as the extrusion temperature increased in the lemon fiber added pasta but not in the pasta without fiber. The rehydration rate also increased by adding lemon fiber. The addition of lemon fiber made the color of dried pasta darker and less yellow. The ratio of soluble and insoluble fiber in the pasta was not affected by extrusion temperature conditions. SEM images showed more disorganized and uneven structure in the pasta produced with lemon fiber, and more consolidated structure in the pasta produced at high temperature.

Keywords: Pasta, Fiber, Extrusion

ÖZ

LİF İÇERİĞİ VE EKSTRÜZYON KOŞULLARININ MAKARNA KALİTESİ ÜZERİNE ETKİSİ

Solta Civelek, Sezil
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Hem ham maddelerin özellikleri hem de işleme koşulları makarna kalitesinin belirlenmesinde önemli rol oynar. Makarnanın ana bileşen maddesi amber sarısı rengi ve içerdiği yüksek miktardaki gluten proteini sebebiyle makarnalık buğday irmiğidir. Makarnanın besin değerini arttırabilmek için makarna daha farklı tahıllar, alternatif tahıllar, tam buğday unu ya da lifler ile zenginleştirilebilir. Fakat, makarnalık buğday unu ile bu ham maddelerin birlikte kullanımı makarnanın kalitesi üzerinde olumsuz bir etkiye sahiptir. Bu çalışmanın amacı makarnaya %5 oranda limon lifi ilave edilmesinin ve ekstrüzyon koşullarının makarnanın kalitesine etkisini incelemektir. Numuneler ekstrüderde iki sıcaklık setinde üretilmiştir: düşük sıcaklık (DS) olarak adlandırılan 40 ºC, 40 ºC, 65 ºC, 45 ºC (kalıp: 55 ºC) ve yüksek sıcaklık (YS) olarak adlandırılan 65 ºC, 65 ºC, 85 ºC, 70 ºC (kalıp: 80 ºC). Bu çalışmada hem limon lifi ilavesinin hem de ekstrüzyon sıcaklıklarının pişirme süresini, pişme kaybını ve ürünlerin tekstür özelliğini etkilemediği görülmüştür. Ekstrüzyon sıcaklığı arttığında daha yüksek şişme indeksi görülmüştür. Limon lifi ilavesinin düşük sıcaklıkta şişme indeksi üzerinde etkisi yokken yüksek sıcaklıkta şişme indeksini arttırmıştır. Ekstrüzyon sıcaklığı arttıkça ve makarnaya limon lifi ilavesi yapıldıkça su tutma indeksi artmıştır. Limon lifi eklenmiş makarnanın ekstrüzyon sıcaklığı arttıkça

rehidrasyon oranının arttığı gözlemlenmiştir. Rehidrasyon oranı limon lifi eklendiğinde de artmıştır. Limon lifi ilavesi kurutulmuş makarnanın rengini daha koyu ve daha az sarı hale getirmiştir. Makarnadaki çözünen ve çözünemeyen lif miktarı ekstrüzyon sıcaklığı koşullarından etkilenmemiştir. Limon lifi ile üretilen makarnalarda daha düzensiz ve dengesiz bir yapı, yüksek sıcaklıkta üretilen makarnalarda ise daha birleşmiş yapı görülmüştür.

Anahtar Kelimeler: Makarna, Lif, Ekstrüzyon

to my precious parents…

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INTRODUCTION

1.1. Pasta

Pasta has been a major food in different territories and cultures, thanks to its favorable production, storage, transportation, and cooking characteristics. There are several different theories about the origin of pasta. One of these theories says that Marco Polo brought information about pasta made with flour to Italy after his visit to China at the end of the thirteenth century (Giacco, Vitale, & Riccardi, 2015). This means varieties of pasta had been already consumed in China before this time. The other theory claims that the history of pasta dates further away in Italy because the word "macaroni" has been found in the Roman Empire sources since the 1st century BC (Giacco et al., 2015). According to the information in the Serventi & Sabban (2002), Arabs invented dry pasta before Italians did, and introduced pasta to many cultures by means of their nomadic lives. Pasta is an advantageous food for them in terms of ease in transportation and feeling of fullness. On the other hand, another group who says they discovered pasta is Koreans. They even tell that they taught to make noodles called "soba" to the Japanese in 12th century (Toussaint-Samat, 2009). Looking at all these theories, it can be said that pasta is very popular and desired to be owned all over the world.

According to International Pasta Organization (IPO) survey, global dry pasta production has reached 14.3m tons in 2015. Italy has the highest annual production capacity with 3.27m tons while USA (2.00m tons), Turkey (1.32m tons), Brazil (1.20m tons), and Russia (1.08m tons) follow with over-million capacities (Table 1.1). When categorized into continental percentages, European Union leads with 34.4%, while Central and South America have 21.7%, North America has 14.9%, other

European countries have 17.0%, Africa has 5.8%, and Middle East has 4.1% of the global production. When consumption statistics are analyzed, Italy again leads distinctly as Italian people consume 23.5 kg’s of pasta per capita each year, on average (Table 1.2). Italy is followed by Tunisia (16.0 kg), Venezuela (12.0 kg), Greece (11.2 kg), Switzerland (9.2 kg), Argentina (8.8 kg), and USA (8.8 kg) (UN.A.F.P.A., 2016). In Turkey, this value is around 7.5 kg. This value in Turkey as in the world increases year after year (International Pasta Organization, n.d.). On the other hand, based on International Trade Center (ITC) statistics (2019), Turkey is in the second rank of world ranking in terms of “Quantity exported in 2018” after Italy.

Table 1.1. World Pasta Production Amount

Country	Production Amount (ton)	Country	Production Amount (ton)	Country	Production Amount (ton)
Italy	3,246,488	Poland	160,000	Switzerland	43,140
U.S.A.	2,000,000	Japan	144,500	Bolivia	43,000
Turkey	1,315,690	Canada	136,000	U.K.	35,000
Brazil	1,204,900	Chile	128,480	Costa Rica	25,182
Russia	1,083,000	Colombia	118,647	Netherlands	23,335
Iran	560,000	India	100,000	Slovak Rep.	22,000
Egypt	400,000	Belgium	77,500	Sweden	20,200
Argentina	381,908	Portugal	76,500	Jordan	20,000
Tunisia	335,500	Czech Rep.	70,000	Crotia	13,000
Germany	332,214	Hungary	66,000	El Salvador	13,000
Mexico	330,000	Dominican R.	65,000	Syria	9,005
Venezuela	329,948	Ecuador	56,000	Slovenia	6,045
Peru	286,089	Austria	54,778	Lituania	5,976
Spain	260,288	Romania	52,600	Panama	4,364
France	237,157	Australia	50,000	Latvia	1,845
Greece	170,000	Guatemala	44,266	Estonia	1,400

Table 1.2. Pasta Consumption in Countries

Country	Cons. (kg/ capita)	Country	Cons. (kg/ capita)	Country	Cons. (kg/ capita)
Italy	23.5	Uruguay	7.5	Poland	4.4
Tunusia	16.5	Croatia	7.3	Latvia	4.1
Venezuela	12	Austria	7.0	Dominican R.	4.0
Greece	11.2	Portugal	6.6	Australia	4.0
Switzerland	9.2	Canada	6.5	Israel	4.0
Argentina	8.8	Slovenia	6.4	Ecuador	3.9
U.S.A.	8.8	Czech Rep.	6.4	Panama	3.8
Iran	8.5	Brazil	6.0	U.K.	3.5
Chile	8.5	Belgium	5.4	Finland	3.2
Germany	8	Estonia	5.3	Guatemala	3.0
France	8	Spain	5.0	Colombia	2.7
Peru	7.8	Slovak Rep.	5.0	Mexico	2.7
Russia	7.8	Bolivia	4.8	Romania	2.7
Sweden	7.7	Costa Rica	4.4	Denmark	2.0
Turkey	7.5	Netherlands	4.4	Libya	2.0
Hungary	7.5	Lituania	4.4	South Africa	1.9

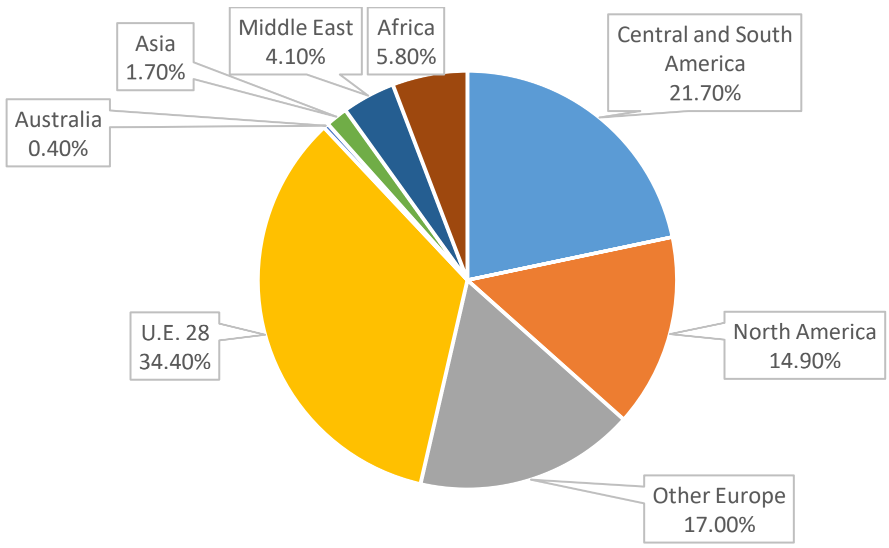

Figure 1.1. Continental Percentage of Pasta Production

Pasta is defined in the Turkish Food Codex as follows: Pasta is a product obtained after shaping and drying of dough prepared by adding water to the semolina produced from *Triticum* durum wheat. According to content, it is called with different names: plain, whole wheat, seasoned, enriched pasta and vitamin and mineral supplemented pasta (Tarım ve Köy İşleri Bakanlığı, 2002a).

There are three main processes in pasta production. In the first step, durum wheat semolina is mixed with water in order to reach required moisture before extrusion. In this part, water temperature and semolina particle size are important parameters. In order to decrease mixing time and getting more homogenous semolina hydration, water at a temperature higher than room temperature (around 40ºC) and smaller particle size semolina (generally 250-350 μm) are preferred in the continuous process (Sicignano, Di Monaco, Masi, & Cavella, 2015). Semolina and water are first mixed in the high-speed premixing unit since this provides the uniform hydrated dough by giving chance to water droplet and semolina particles contact each other. After high-speed premixing unit, semolina-water mixture comes to the main mixing unit. This unit is generally under vacuum in order to remove air bubbles. These air bubbles cause some problems like non-uniform color, cracking risk in pasta (Bustos, Perez, & Leon, 2015). In the second step, the prepared dough comes to the extruder unit, which has a mechanical work that provides the development of the gluten network surrounding the starch granules. This helps the pasta keeping its structure stable during cooking. The dough transported by screw(s) in the extruder unit passes through the die under high pressure in order to take shape. The pasta passed through the die is immediately cut, and goes to the third step of production, drying. When the final product quality like color, cooking behavior, surface texture etc. is examined, it can be said that the most critical and difficult part in pasta production is drying (Giacco et al., 2015; Piwińska, Wyrwisz, & Kurek, 2016). The aim of drying is to decrease the moisture content of pasta from near 31-32% to 12-13% by using high/very high temperature 60-90ºC using the latest technology (Bustos et al., 2015; Giacco et al., 2015; Güler, Köksel, & Ng, 2002). In traditional drying system, temperature is between 40ºC and 60ºC.

However, some researchers say that high/very high temperature reduces drying time, increases hardness in cooked pasta, improves the final product color, decreases microorganisms (Güler et al., 2002; Sicignano et al., 2015). Dried pasta can be stored easily at room temperature for many years without spoiling, keeping its shape.

In pasta quality, raw material properties also play an important role besides the parameters of the pasta production process. Thanks to intense yellow color, yummy taste and providing strong structure, durum wheat (*Triticum durum*) semolina is preferred to make pasta instead of common wheat (*Triticum aestivum*) flour generally used for bread or noodles. Some countries like Greece, Italy (for special pasta) or France have legislation about using only durum wheat semolina in pasta production ("Pasta Legislation In The EU," 2001). In Turkey, pasta production is also restricted with using durum wheat semolina (Tarım ve Köy İşleri Bakanlığı, 2002b). Durum wheat proteins consist of 20% albumin (soluble in water), globulin (soluble in salt solution) and 80% monomeric gliadin (extractable in aqueous ethanol solution) and polymeric glutenin (soluble in dilute acid) (Sicignano et al., 2015). These proteins make entangled aggregation which strengths pasta structure while starch in durum wheat semolina appears as dispersed granules within this protein network (Giacco et al., 2015). When semolina is produced from durum wheat with high protein content and has a uniform particle size with a minimum number of starchy particles, it can hydrate homogenously. This provides more strong and elastic pasta structure. In addition, this provides less organic residue passing from pasta to the cooking water (Sissons, 2008). Sicignano et al. (2015) written the generally accepted issue that the interactions between glutenin and gliadin affect the gluten quality that has an important role in pasta quality. Glutenin is responsible for elasticity of gluten, while gliadin is related to the extensibility of gluten. It is known that there are two main subunits of glutenin; low molecular weight glutenin subunit (LMW-GS) and high molecular weight glutenin subunit (HMW-GS) (Joan Subira, Roberto Javier Peña, Fanny Álvaro, Karim Ammar & Royo, 2014). These subunits have an important impact on gluten strength. LMW-GS, which is rich in sulfur, has one or two free cysteine residues in intermolecular disulfide bonds, while HMW-GS, which is poor in sulfur, has two to five (D'Ovidio & Masci, 2004). According to current model for gluten network structure proposed by Shewry et al. (2001), HMW-GS provides the main backbone by constituting disulfide bonds between HMW-GS chains. Meanwhile, LMW-GS acts as chain connector thanks to free sulfhydryl groups. In order to complete this network structure, gliadin is linked to HMW-GS chains via non-covalent bonds. Firmness and toughness properties of this gluten network structure is related to the ratio of polymeric glutenin to monomeric gliadin. Besides importance of protein content of durum wheat semolina, starch has also some important effects on rheological properties of pasta. Starch granules in two different sizes (small spherical one and large lenticular one) have a role in some cooking quality like firmness, stickiness, cooking loss. Soh, Sissons, & Turner (2006) obtained in their study that as the number of small spherical starch granules increased, water absorption and firmness of pasta also increased and stickiness decreased slightly. In addition, they also observed that as the amylose content in starch increased, the dough was more extensible, the cooked pasta firmness increased and the pasta water intake decreased.

Since the unspecified start of pasta, a lot of research has been done in areas such as pasta quality, content, production methods, and varieties. Some researchers focused on the effect of raw material on the quality of pasta (L Padalino et al., 2015; Soh et al., 2006). Some of them investigated the effect of material, which makes the pasta functional food, on the quality of pasta (Aravind, Sissons, & Fellows, 2012; Aravind, Sissons, Fellows, Blazek, & Gilbert, 2012a; Bustos, Pérez, & León, 2011). There are also some researches related to production methods like different drying conditions (Piwińska, Wyrwisz, Kurek, & Wierzbicka, 2015; Piwińska, Wyrwisz, Kurek, & Wierzbicka, 2016). In all these pasta researches, the quality of the pasta is generally evaluated in terms of the following parameters: cooking loss, swelling index, water absorption, color, textural properties. In Turkey, there is a legal limit only for "cooking loss" parameter (Tarım ve Köy İşleri Bakanlığı, 2002b). Although the other parameters do not have legal restriction, they are used for consumer acceptance.

There are many different pasta consumption habits in different parts of the world. Pasta can be consumed either as a main course or as a snack. It can be easily diversified in terms of content and shape. This diversity can easily be provided by adding new raw materials to the pasta and attracts the attention of consumers both in terms of health and visually. After the Food and Drug Administration of the United States (FDA) permitted using vitamins for the enrichment of pasta in 1949 (Brennan & Zealand, 2013), a lot of research related to enrichment/fortification of pasta has been done. As can be seen from these studies, besides using whole wheat flour (Kalnina, Rakcejeva, Kunkulberga, & Galoburda, 2015; L Padalino et al., 2015), protein source (Jayasena & Nasar-Abbas, 2012), vitamins (Rawat & Indrani, 2015), adding fiber to pasta is one of the most studied subjects because of scientific evidence showing beneficial effects on health (Chater, Wilcox, Pearson, & Brownlee, 2015; Dreher, 2018; Gao & Yue, 2012; Kritchevsky, 1974; Mirmiran, Yuzbashian, Asghari, Sarverzadeh, & Azizi, 2018).

In addition to pasta research as a functional food, research on ready-to-eat/precooked pasta has started to be carried out, as the demand for fast food products increases (Wojtowicz, 2005; A. Wójtowicz & Mościcki, 2009; Agnieszka Wójtowicz & Mościcki, 2014). There are several ways to make precooked pasta: frying (Ding & Yang, 2013), steaming (Ding & Yang, 2013; Kaur, Sharma, Nagi, & Ranote, 2013) and extrusion cooking (Wojtowicz, 2005; A. Wójtowicz & Mościcki, 2009; Agnieszka Wójtowicz & Mościcki, 2014). In the frying method, fresh pasta was fried at 140 to 160ºC for 30 to 70s or fried at 148ºC for 120s. In steaming method, the fresh pasta was steamed at 95 to 98ºC in a steamer for 180 s. Among these, extrusion cooking is one of the most preferred methods in the food industry because of its low cost, energy efficiency and lack of waste problems (Chuang & Yeh, 2004).

1.2. Dietary Fiber

“Dietary fiber” was first described as non-digestible part of plants by Eben Hipsley in 1953 (Hipsley, 1953). These parts are known as non-digestible polysaccharides mainly like cellulose, hemicellulose, lignin etc. In 70's, Trowell expanded the definition of dietary fiber. He said that they are edible plant cell residues that are resistant to digestive enzymes of humans (Panel on the Definition of Dietary Fiber, Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, 2001). As studies on dietary fibers increase, relevant updates with the definition of dietary fiber is still ongoing. Nowadays, the definition of fiber which is also explained in European Parliament and Council (2008) is defined as: "carbohydrate polymers with three or more monomeric units, which are not hydrolyzed, digested or absorbed by endogenous enzymes in small intestine of human beings". Fibers are grouped into two categories (Vergara, 2013):

1) Soluble fibers, that are totally fermented in the colon, as they can dissolve in water. (Gums, pectin, β-glucans, mucilages etc.) They are useful in lowering cholesterol and regulating glucose in blood (Tosh & Yada, 2010).

2) Insoluble fibers remain mostly undigested (cellulose, hemicellulose, lignin, etc.). They help the movement of food through the small & large intestines. Most of these fibers are fermented in the large intestine, thus the growth of intestinal microflora with probiotic species is supported.

The transition from nomadism to permanent settlement, with agriculture and animal husbandry, has drastically changed the diet of human. It was previously based on various types of foliage, leafy vegetables, fruits, seeds, and nuts, all of which have low glycemic load and high fiber content (Cordain, 2007). This change was not a big problem until 1800s. With industrial revolution, people started to consume processed food with lower fiber and animal products more. Combined with less active lifestyle (due to advances in transportation), this change led to a significant rise in cardiovascular diseases, diabetes, and cancer. Between the late 1960s and the early 1970s Burkitt's studies initiated the interest on dietary fiber as a mean to prevent and manage chronic diseases (Cummings & Engineer, 2017).

Gao & Yue (2012) explained that when the benefits of dietary fibers are examined in detail, soluble and insoluble fibers have different effects. Soluble fibers slow food out of the stomach and the passage of food through the small intestine. They have no big effect on fecal bulk. On the other hand, insoluble fibers accelerate the passage of food through the intestine, and they increase the fecal bulk. In terms of cholesterol, they mentioned many research related to reducing effect of soluble fiber while saying insoluble fibers have no effect on reducing cholesterol. Besides, insoluble fibers have significant effects on intestinal regularity and presence of fecal bulk.

Lattimer and Haub (2010) mentioned in their article that the other effect of dietary fiber is loss in body weight. There are two correlation conditions between dietary fiber consumption and obesity, depending on the fat level of the diet. When soluble fibers are added in a low-fat diet, they have an effect of decreasing metabolizable energy that is difference between gross energy and energy lost in all solid, liquid, gas exits from the body. In contrast, they increase the metabolizable energy if they are consumed in a high-fat diet. On the other hand, the exact opposite situation is valid for insoluble fibers. In order to decrease body weight, insoluble fibers should be consumed in a high fat diet since this decreases the metabolizable energy. Lattimer and Haub (2010) also mentioned about relation between diabetes and dietary fiber consumption. Soluble fibers except guar have no effect on the risk of Type-II diabetes while insoluble fibers have a strong inverse effect on that. On the other hand, since having the highest viscosity, guar has an effect on rising postprandial blood pressure. Therefore, there is a relation between guar consumption and decrease in the risk of diabetes.

Glycemic index (GI) is a scale used to indicate the rate at which a food containing carbohydrates increases blood glucose (M. Foschia, Peressini, Sensidoni, Brennan, & Brennan, 2014). Foods are classified between 0-100 according to the glycemic index. Since glucose increases postprandial blood glucose level very quickly, its glycemic index is considered 100; and, it is a reference for other foods. Generally, most breads and breakfast cereals are classified as high GI, which is more than 90. Foods like oatmeal, bran, sweet potatoes are in medium GI class, which is generally in range 65-89. The last class is low GI foods. Generally, pasta, legumes, nuts etc. are in this class. According to blood glucose profiles, low GI foods are thought to have a beneficial metabolic effect that is decreasing glucose absorption in the small intestine. This effect of low GI foods also induces a lower increase in insulin circulation and regulates intestinal hormones. These features at the same time provide counter-regulating hormones produced by force of high blood glucose oscillations and suppression of fatty acids. Insulin receptor sensitivity increases with time due to the decrease in free fatty acid levels. Therefore, glucose is returned from the circulation at a higher rate. As a result, blood glucose levels continue being at the level that is close to the baseline, although absorption of glucose from the small intestine continues. Thus, increase in peak of postprandial blood glucose decreases with increasing blood glucose above the baseline. This significantly enhances the blood glucose control that is an important parameter for people with insulin resistance and diabetes. Hence, low GI foods (with high fiber) can provide glycemic control, and help body weight balance (Kendall, Esfahani, & Jenkins, 2010).

Despite its health benefits, the use of dietary fiber in pasta production may cause changes in the quality characteristics of pasta. The quality of pasta depends on physical, chemical, textural, and nutritional characteristics. Consumers appreciate cooking quality by observing or feeling apparent factors like “cooking time, swelling or water uptake during cooking, texture of the cooked product, stickiness, aroma, and taste”. All of these factors depend on the chemical composition and gelatinization rates of the pasta.

As Tudorică, Kuri, & Brennan (2002) show, enriching pasta with dietary fibers affects these factors, in positive or negative ways, depending on the type and amount of the fiber. They investigate characteristics of pasta with no fiber (as a control product), pasta with pea fiber (at 7.5, 10, 12.5, and 15% concentration); inulin (at 7.5, 10, 12.5, and 15% concentration); and guar gum (at 3, 5, 7, and 10% concentration). According to their measurements, guar increases the swelling index of pasta by 10%, while other fiber does not make a significant change. The addition of pea fiber or inulin, on the other hand, increases cooking loss, and solids loss, due to the disruption of the protein network. Guar gum, however, leads to reduced (guar at 3%) or similar cooking and solids losses (guar at 5, 7, and 10%). Pasta with pea fiber (7.5 and 15%) and guar (10%) have lower firmness. Samples containing inulin or guar have lower elasticity.

In another study (Lucia Padalino et al., 2014), spaghetti samples are fortified with multiple fibers. In contrast to Tudorică, Kuri, & Brennan's work (2002), pea flour addition leads to lower swelling index and higher firmness in this study. When combined with unpleasant color and odor, these changes decrease the quality of the product. Thus, researchers use guar gum as a second additive to improve the sensory quality, especially for a more pleasant color, odor, and taste. The sample with pea flour and guar gum has higher soluble fiber content (lower glycemic index), and lower starch digestibility.

Piwińska, Wyrwisz, Kurek, et al. (2016) studied the effect of oat β-glucan fiber on cooking quality and physical properties of pasta. Researchers examined that pasta with 4%, 8%, 12%, 16% and 20% concentration of oat β-glucan fiber have the same optimal cooking time while they provide more water absorption than pasta with no fiber done. On the other hand, they found that the percentage of fiber concentration affects some quality parameters. For example, the swelling index did not show significant difference up to 8% concentration level of fiber added pasta; however, there was significant increase for the higher concentrations. It was seen that oat β-glucan fiber also affects the pasta color significantly at all concentrations.

There is another research using another cereal product, wheat bran. This study was carried out by Sobota et. al. (2015) in order to examine the quality changes of pasta in industrial production. They performed measurement of pasta made with 20%, 25%, 30%, 35% and 40% added wheat bran to wheat semolina. In order to compare results, pasta made from whole grain durum wheat flour was used. Although the cooking loss of pasta containing 20% wheat bran is lower than that of the reference, as the amount of wheat bran increased in pasta, cooking loss also increased. According to sensory analysis results, reference sample had the highest score because of its brightness, glassy and uniform semi-transparent color. Panelist rated low taste of pasta because of aftertaste of bran in the mouth. They observed that the pasta harder as the amount of fiber increased.

Bustos et al. (2011) used four types of dietary fiber in their research by using pasta with no fiber as a control in order to examine the quality changes of pasta. These fibers Resistant starch II (RS-II), Resistant starch IV (RS-IV), oat bran, and inulin was added to wheat flour at 2.5%, 5.0%, 7.5%, and 10% concentration. In this research, different from the others, they investigated the microstructure of cooked pasta to show the integrity of protein-starch structure in fiber enriched pasta. First, image of reference sample showed that there were gelatinized and enlarged starch granules in the protein matrix besides a few non-gelatinized ones. On the other hand, pasta enriched with RS-IV had similar image with that of reference, but higher degree of gelatinization of starch molecules was seen. In the image of pasta enriched with RS-II, a denser protein-polysaccharide-protein structure was observed. Contrary to these observations, it was seen in the images of pasta enriched with oat bran that there was a weaker protein network, and starch granules were not fully incorporated into the structure. There were many holes between protein and starch molecules.

Some of the vegetable flours can be used as dietary fiber for enrichment of pasta. In connection with this, there is research made with lupin flour (Jayasena & Nasar-Abbas, 2012). It was substituted with durum semolina at the rate of 0% (as control), 10%, 20%, 30%, 40% and 50%. Optimal cooking time (OCT) of pasta containing up to 30% lupin flour was not affected significantly. However, OCT of pasta with 40% and 50% lupin flour significantly increased. There was no significant difference between all of the lupin flour concentrations in terms of cooking loss. The color of uncooked pasta showed significant difference for the pasta containing above 20% lupin flour in terms of L* and b* value. Sensory analysis included color, appearance, taste and texture parameters. Thus, overall acceptance of pasta samples with up to

20% lupin flour showed no significant difference. Scores for substitution greater than 20% showed a significant decrease.

As seen from the above studies, pasta quality is not evaluated with a single parameter. In addition, different types of fibers have different effects on the quality of pasta at different substitution levels.

1.3. Extrusion Technology and Extrusion-Cooking

Market for extruded products is expanding, since extrusion is a solid method for creating new and creative products from inexpensive raw materials, in short processing time. “Extrusion’ which originally comes from the Latin word “extrudere” literally means that the motion of pushing something out. According to the engineering approach, extrusion describes the process of removing material from a narrow gap by pressure (Paisaje & Paisaje, 2009).

Extrusion technology has been used in the polymer industry, pharmaceutical industry, food industry, etc. for a long time (Chuang & Yeh, 2004; Dyadichev, Kolesnikov, Menyuk, & Dyadichev, 2019; Galland et al., 2003). The application of extrusion technology in food products was developed after the second world war in order to make industrial pasta production (Le Roux, Vergnes, Chaurand, & Abécassis, 1995). At first, food extrusion was limited mixing and shaping of pasta. As it can be seen in Table 1.3, there have been continuous developments in the extrusion technology used in the food industry (Paisaje & Paisaje, 2009).

Table 1.3. Development of Extrusion Technology in the Food Industry

Year	Equipment	Commercial Uses
Prior to 1950	Non-thermal extruder, forming	Pasta
1950	Single screw cooking extruder	Dry animal feed
1960	Single screw cooking extruder	Texturized vegetable protein, ready-to-eat cereals, puffed snacks, pellets, dry pet foods
1970	Twin screw cooking extruder	Moist pet food, upgrading raw material
1980	Twin screw cooking extruder	Flat bread, croutons, confectionary, chocolate
1990	Twin screw with long cooling dye	Moist texturized proteins
2000	Refrigerated extruder	Ice cream, frozen bars

After the 1950s, researches on extrusion cooking developed. It is highly preferred in food industry, as its control is automatic, its capacity is scalable, and its operation is continuous and adaptable. Moreover, extrusion requires less energy, when compared to other processing methods, and it enables unique product characteristics by modifying the structure, improving the solubility, swelling power, water hydration viscosity and water holding capacity (Faraj, Vasanthan, & Hoover, 2004). Extrusion cooking is a kind of thermomechanical process that includes heat and mass transfer, shear and pressure changes in order to provide the used material mixing, conveying, kneading, melting, cooking, texturizing, puffing, forming, etc. (Emin, 2016). This thermal and mechanical energy which are provided by means of heated barrels and rotating screws in the incorporate extrusion system cause some structural, chemical or nutritional changes like protein denaturalization, starch gelatinization, lipid oxidation, increase of dietary fiber solubility etc. (Ficarella, Milanese, & Laforgia, 2006). Therefore, it can be said that the extruder is an equipment formed in the combination of heat exchanger, continuous high-temperature high-pressure reactor and pump (Paisaje & Paisaje, 2009). Although the content of the raw material used in the extrusion is generally the same, like starch, proteins, and lipids, the characteristics of the final products are affected by the chemical composition of these substances and extrusion parameters like temperature, screw rotational speed, moisture content of dough (Giménez et al., 2013; Manthey, Patel, Campanella, & De, 2014; Seker, 2005).

Giménez et al. (2013) studied how extrusion conditions affect physicochemical and sensorial properties of corn and broad beans-based spaghetti. Pasta dough was prepared at three different moisture content (28%, 31% and 34%) and it was produced at three different temperatures (80, 90 and 100 ºC). They evaluated the parameters like expansion, cooking loss, water absorption, firmness, and stickiness. They found that expansion increases and cooking loss decreases as the moisture of dough decreases and the extrusion temperature increases. Water absorption was limited at the highest level when spaghetti produced from 28%, 31% at 100ºC. In sensorial analyses, trained persons gave the highest score for firmness and stickiness to spaghetti produced at the highest temperature from the lowest moisture content.

Some research has shown that the mechanical forces applied on the fibers affect some physical properties like water holding properties of the fibers. As an example, stirring helps the fiber to open its structure, thus free hydroxyl groups can easily bind with water (Sangnark & Noomhorm, 2003). For another example, grinding may cause an increase or decrease in the water holding properties of dietary fiber depending on fiber's particle size after process (Zhu, Du, & Li, 2014). Besides the mechanical forces, thermal treatments can affect the ratio of soluble and insoluble parts (Elleuch et al., 2011). In Elleuch et al. (2011)'s research, extrusion process is explained as a process that can change the structure or properties of dietary fibers because foodstuffs are exposed to heat under pressure in the extruder. When sugar beet pulp (Rouilly, Jorda, & Rigal, 2006) and black bean (Camara, Torua, & Alonso, 2002) were used in twin screw extruder, the amount of soluble fiber increased.

In food industry, three types of extruders are utilized; piston extruders, roller-type extruders, and screw extruders. In recent research, the most widely used extruder type is screw extruder. In this type of extruder, the dough-like raw material is conveying by rotating screw(s) through the barrel, which is heated by steam or electric power.

System is also heated by the mechanical energy which arises from the rotating screw and friction inside the barrel (Alam, Kaur, Khaira, & Gupta, 2015). Screw extruder is divided into 2 categories: single screw and twin screw.

Single screw extruder contains three sections: feeding, transition and melting/degradation. Materials with a high coefficient of friction are easier to process in single screw food extruders. However, since mixing in single screw extruder is poor, this operation should be done before. Another disadvantage of single screw extruder is that its efficiency reduces when raw materials having different components is used. Twin-screw extruder has a more complicated design that is its disadvantage. Even though, it has become popular because of its ability to process a wide material range including viscous and hard to break materials. It is divided into 2 types in terms of the direction of screw rotation: co-rotating and counter rotating. Due to the good efficiency of conveying of material, good mixing, its high productivity, co-rotating type is more preferred (Mościcki & van Zuilichem, 2011).

Pasta extruder is also known as cold extrusion since it contains only mixing and forming parts operating at a maximum 40-50ºC. However, there are also some studies in which extrusion cooking method using high temperature is applied to make pasta can be cooked more quickly. According to Rafiq, Sharma, & Singh (2017), although single screw extruders are generally used in pasta production, twin screw extruders can be also used. Wójtowicz & Mościcki (2011) used single screw extruder in order to make precooked pasta with the addition of wheat bran to wheat flour. They have studied how wheat bran and screw rotation speed of extruder affect the microstructure and texture properties of the precooked pasta. For extrusion cooking, the barrel temperatures were adjusted 85 ºC, 100 ºC, and 75 ºC, from input part to output part, respectively. Pasta produced using four different screw rotation speeds (60, 80, 100 and 120 rpm) and five different bran addition rates (5, 10, 15, 20 and 25%). They concluded that both the addition of bran and the screw rotation speed resulted in the quality of the pasta. Lower screw rotation speed caused some ungelatinized starch granules and unconverted wheat bran fractions, in contrast higher speed provided the deterioration of wheat bran cell walls. Hardness of dry-pasta products decreased as screw rotational speed and bran addition rate increased. In addition, firmness of hydrated pasta also showed a tendency to decrease as the amount of bran addition rates increased. At low screw rotational speed, great stickiness and adhesiveness was observed which caused poor quality pasta. Addition of wheat bran caused a decrease in L* value of both dry and hydrated pasta.

In another research, Rafiq et al. (2017) investigated the effects of three independent variables, which were feed moisture (28, 32 and 36%), barrel temperature (30, 40, 5070, 90 and 110ºC) and brown rice ratio (10, 20 and 30%), on pasta quality using twin screw extruder. They found that the degree of gelatinization increased in direct proportion to the feed moisture and barrel temperature, while the addition of legume affected inversely. It was also seen that there was a direct correlation between these three parameters and water absorption capacity. On the other hand, it was investigated that cooking loss increased with increasing feed moisture and brown rice ratio and decreased with increasing barrel temperature.

1.4. Aim of the Study

The awareness about the benefits of dietary fibers has recently increased, globally. As most of the health problems are associated with fast food and junk food consumption, the need for functional foods has become prevalent. Pasta, in this context, is a powerful candidate for enriching diet, especially for busy professionals, who have a limited amount of time for cooking, and for children, who already love eating pasta.

When the studies on dietary fiber were examined, it was seen that interest in adding fiber to pasta increased day by day. As can be seen in these studies, it has been focused on the addition of fibers of foods such as cereals and vegetables to pasta. Although it can be commented on lemon fiber based on its soluble/insoluble properties, a study using this fiber in pasta is not available in the literature.

On the other hand, a new trend in food production is combining extrusion and cooking in a single process, i.e. extrusion cooking. Some of the recent studies focus on the application of this method in pasta production.

In this study, it was aimed to evaluate the effect of lemon fiber addition and barrel temperatures on the quality of pasta. It was investigated that how our dependent variables which are expansion ratio, optimal cooking time, cooking loss, swelling index, water absorption capacity, rehydration rate, gelatinization degree, color, textural properties, microstructural properties were affected. The change in soluble and insoluble fiber content during processing was also studied.

CHAPTER 2

MATERIALS AND METHODS

2.1. Materials

Durum wheat semolina which is the basic raw material used for pasta preparation was supplied from Nuh'un Ankara Makarnası (Ankara, Turkey). According to the supplier's information, the granulometry of durum wheat semolina was under 450 µm, mostly around 250 µm. Durum wheat semolina had 12.85% protein and 0.72% ash content. Its gluten index was 67%. Lemon fiber, which has 22.51 g water/g solid water binding capacity, was provided from Arosel Gıda Ltd. Company (Istanbul, Turkey).

2.2. Methods

2.2.1. Pasta Preparation

Two types of pasta dough was prepared for the study. One of the dough was made from only durum wheat semolina and water (control). In the other one, %5 of durum wheat was replaced by lemon fiber. Moisture content of durum wheat semolina and lemon fiber was measured with halogen moisture analyzer (MB45, Switzerland) at 105°C. Then, a mixture of durum wheat semolina-water and durum wheat semolina-water-lemon fiber was prepared to have a 30% moisture content with the help of the mixer (Kitchen Aid, USA). In order to prevent aggregation of semolina, water at room temperature was slowly added during mixing, which takes approximately 10 min. The prepared pasta dough was kept at the refrigerator (4°C) overnight. Two hours before extrusion process, the pasta dough was put at room temperature (20±2°C) to equilibrate.

In the study, a laboratory scale co-rotating twin-screw extruder (Feza Gıda Müh. Mak. Nakliyat ve Demir Tic. Ltd. Şti,, Turkey) with data acquisition system and computer control was used for making pasta. The barrel length to diameter ratio (L/D) and the diameter of die with one circular opening were 25:1 and 1 mm, respectively. There were four heating zones, which were controlled by electrical heating and water-cooling. By using a computerized data acquisition system, barrel temperatures, screw speed and flow rate were adjusted to set values. The prepared dough was fed to the extruder with the help of the twin-screw volumetric feeder integrated with the extruder system.

The feed flow rate and screw speed were 15 ± 1 g/min and 200 rpm, respectively for all samples. We determined the extruder temperatures according to the lowest and highest temperature conditions that we can use in the extruder after preliminary experiments. According to this, the barrel temperature zones were set at 40°C, 40°C, 65°C, 45°C (Die: 55°C) and 65°C, 65°C, 85°C, 70°C (Die: 80°C). Pasta sample was taken if and only if actual measured barrel zone temperatures and die temperatures were in the range of ± 2°C of set temperatures.

After extrusion, pasta were cut into 5 cm pieces and dried for 12 hours at room temperature (20±2°C) and 36-58% relative humidity (RH), measured with a temperature and humidity measurement device (EBRO EBI 20-T1, Germany), in order to bring its moisture content to 10 ± 1 %. Dried pasta were kept in closed plastic bags at room temperature (20±2°C) until the analysis.

2.2.2. Physical Properties

2.2.2.1. Expansion Ratio (ER)

A digital caliper (SR-44, Insize, Turkey) was used for the determination of the diameter of dried pasta. Measurement was done for one hundred pasta pieces chosen randomly for each extrusion condition after drying of pasta. Expansion ratio (ER) was calculated using the equation below (Wojtowicz, 2005):

$$ER = \frac{D_e}{D_d}$$

Where; D_e : Diameter of the pasta (mm) & D_d : Diameter of the die (mm)

2.2.2.2. Optimal Cooking Time (OCT)

Optimal cooking time was determined according to AACC Method 66-50, formerly 16-50 “Pasta and Noodle Cooking Quality – Firmness” (AACC, 2000). A 5 g of pasta was put into the beaker containing 100 mL boiling distilled water (ratio of sample to cooking water should be at least 1:10), and stirred in order to separate pieces. The beaker was covered partially to decrease evaporation and extra boiling water was used to provide cooking water volume to be at least 90% of the original volume during cooking. A piece of pasta was taken out every 30 s, and squeezed between two glass slides. Optimal cooking time was defined as the time at just center core disappears. This means that starch at the center has just gelatinized.

2.2.2.3. Cooking Loss (CL)

Cooking loss (CL) of each pasta was calculated according to AACC Method 66-50, formerly 16-50 “Pasta and Noodle Cooking Quality – Firmness” (AACC, 2000) with some modifications (Agnieszka Wójtowicz & Mościcki, 2014). 10 g of pasta was cooked in the 200 mL of boiling distilled water for 10 min in a partially covered container to reduce the evaporation of cooking water. Then, the cooked pasta was rinsed with 100 mL of cold water in order to stop cooking and drained for 5 min. The combination of cooking and rinsed water were evaporated to dryness (approximately 20 hours) in an air oven at 105±1°C. Beakers with residue was cooled in the desiccator and weighed to calculate cooking loss. Analyzes were repeated for three times.

$$CL = \frac{W_r}{W_u} \text{x}100$$

Where;

W_r : Weight of the residue from cooking and rinsed water (g)

W_u : Weight of uncooked pasta (g)

2.2.2.4. Swelling Index (SI)

The swelling index (SI), which is the weight fraction of water in the cooked pasta was determined by weighing pasta after cooking (for cooking the same procedure with cooking loss was used) and drying until reaching constant weight in an air oven at 105 ± 1°C (Foschia et al., 2015). Then, the swelling index was calculated as:

$$SI = \frac{W_c - W_d}{W_d}$$

Where;

W_c : Weight of cooked pasta (g)

W_d : Weight of pasta after drying (g)

Analyzes were repeated for three times.

2.2.2.5. Water Absorption Index (WAI)

The water absorption index (WAI) was calculated according to the equation defined by Foschia et al. (2015):

$$WAI = \frac{W_c - W_u}{W_u} \text{x}100$$

Where;

W_c : Weight of cooked pasta (g)

W_u : Weight of uncooked pasta (g)

The cooking procedure was the same as the procedure for cooking loss. Analyzes were repeated for three times.

2.2.2.6. Rehydration Rate

Rehydration rate was measured according to the method described by Nouviaire et al. (2008). 2.5 g of sample was cooked in 100 mL boiling distilled water in a perforated box for 20 min. In each two minutes of cooking process, pasta was taken out of boiling water, drained and weighed. Time of weighing was not placed on timing account. In order to compare rehydration rate of each sample at different conditions, W_i/W_u vs. time graph was drawn, where W_i was the weight of cooked pasta at various cooking times and W_u was the weight of uncooked pasta. Slopes of these graphs were used for comparing rehydration rate of samples. Analyzes were repeated for three times.

2.2.2.7. Gelatinization Degree

The thermal characteristics and gelatinization degree of extruded dried pasta were analyzed using differential scanning calorimetry (DSC). DSC 4000 with Intracooler equipment (Perkin Elmer, Netherlands) was used for this analysis. Indium and zinc were used as standards.

Around 5 mg of ground extruded dried pasta or ground semolina were weighed into the DSC pans (30 μL, Perkin-Elmer). Samples were moistened with 15 mg distilled water that was enough to gelatinize at proper condition. DSC pans were hermetically sealed by the help of a sample encapsulating press system. The closed pans were kept at the refrigerator (4°C) overnight in order to equilibrate.

Before using the equipment, the nitrogen flow rate in the cooling system was set to 20 mL/min. The pans were placed into the DSC cell. At the same time, an empty pan was used as a reference. The DSC cell was heated from 30°C to 100°C at the rate of 10°C/min. Enthalpy of gelatinization (ΔH), gelatinization onset temperature (T_o) and peak temperature (T_p), and end temperature (T_e) were computed using Pyris software (Ver. 11.0.0.0449). Each sample was analyzed at least twice.

2.2.2.8. Color

The color of uncooked pasta was determined by using Spectrophotometer CM-5 (Konica Minolta, Japan) with CIE L^*, a^*, b^* color scale. Pasta pieces, 5 cm in length, were placed in the transparent sample vessel for color measurement, making sure that bottom surface of vessel was fully covered with pasta (Wang, Maximiuk, & Toews, 2012). Standard Illuminant D65 was used, and L^* (lightness), a^* (redness-greenness), and b^* (yellowness-blueness) values were monitored. The measurement was repeated for three times.

2.2.2.9. Texture

Firmness of cooked pasta was determined with the help of a Texture Analyzer (TA HD Plus, Stable Micro System, UK). The equipment having 5 kg load cell and the light knife blade (A/LKB) was used according to AACC Method 66-50, formerly 16-50 “Pasta and Noodle Quality- Firmness” (AACC, 2000).

25 g of pasta was cooked to optimal cooking time in 500 mL boiling distilled water including 4 g of salt. Then, 200 mL cold water was poured onto cooking water in order to stop cooking and filtered. Another 200 mL cold water was poured in filtered pasta, and pasta was drained for 30 s. After holding the pasta in 150 mL cold water for 3.5 min, five strands of 5 cm-long cooked pasta were placed parallel to each other on to the measurement plate of the texture analyzer. Before the analysis, the light knife blade was brought to 5 mm away from the measurement plate. In compression mode, the speeds of the light knife blade before the test, during the test and after the test were 1.00 mm/s, 0.17 mm/s and 10.00 mm/s, respectively. The strain was 90%, and the results, maximum cutting force, were recorded with acquisition rate equal to 400 points per second. The measurement was repeated for two times.

2.2.3. Microstructure of Dry Pasta Products

Microstructure of surface and cross section of uncooked pasta were observed using scanning electron microscopy (SEM, FEI Nova Nano FEG-SEM 430) at 1500× magnification. Before the scanning, pasta were coated with gold. Then, each sample was placed onto the microscope. Images were taken at 20 kV and high vacuum mode.

2.2.4. Dietary Fiber Analysis

Insoluble and soluble dietary fiber of semolina-fiber mixture and pasta with fiber produced at different temperatures were determined according to AACC Method 32-

07 “Determination of Soluble, Insoluble and Total Dietary Fiber in Foods and Food Products” (AACC, 2000).

In 400 mL beaker 40 mL MES-TRIS buffer solution (pH 8.2) and 1.000 ± 0.005 g samples were stirred using a magnetic stirring bar until sample was completely dispersed in buffer solution. Then, this mixture was incubated with 50 µL heat stable α-amylase at 95-100°C for 15 min, 100 µL protease at 60°C for 30 min, and 200 µL amyloglucosidase at pH 4.1-4.8 and 60°C for 30 min. Two blanks were prepared using the same procedure but without sample. After enzymatic digestion ended, mixture was filtered through glass crucible (por.3, 40 µm) including 0.5 g Celite by the help of a vacuum pump (DrVAC-600, Lab312, Taiwan). The crucible including 0.5 g Celite was wetted with 3 mL distilled water before the filtration. The residue containing insoluble dietary fiber was washed twice with 10 mL 95% EtOH and acetone, respectively. The crucibles were dried at 105 ± 1°C overnight.

Filtrate and washing water was transferred to a 600 mL beaker. 95% EtOH was preheated to 60°C. This EtOH with the volume of four times the transferred liquid was added to the same 600 mL beaker in order to form precipitate particles that were soluble part of digestate. After 1 hour waiting, precipitates were filtered through glass crucible (por.3, 40 µm) including 0.5 g Celite by the help of a vacuum pump (DrVAC-600, Lab312, Taiwan). The crucible including 0.5 g Celite was wetted with 15 mL 78% EtOH before the filtration. The residue containing soluble dietary fiber was washed twice with 15 mL 78% EtOH, 95% EtOH and acetone, respectively. The crucibles were dried at 105 ± 1°C overnight.

While one residue from each set of duplicate insoluble dietary fiber was analyzed for protein analysis using Kjeldahl method with 6.25 factor, the other residue was used for ash analysis in a muffle furnace at 525 ± 1°C for 5 hours. Insoluble and soluble dietary fiber was calculated from this equation:

$$Dietary\ Fiber\ (\%) = \frac{\frac{R_1 + R_2}{2} - p - A - B}{\frac{m_1 + m_2}{2}} x100$$

Where;

m_1: Weight of sample 1 (g)

m_2: Weight of sample 2 (g)

R_1: Weight of residue from sample 1 m_1 (g)

R_2: Weight of residue from sample 2 m_2 (g)

p: Weight of protein from R_1 (g)

A: Weight of ash from R_2 (g)

B: Weight of blank calculated from this equation (g):

$$B = \frac{BR_1 + BR_2}{2} - BP - BA$$

Where;

BR_1: Weight of residue from blank 1 (g)

BR_2: Weight of residue from blank 2 (g)

BP: Weight of protein from BR_1 (g)

BA: Weight of ash from BR_2 (g)

2.2.5. Statistical Analysis

All the results were analyzed by one-way analysis of variance (ANOVA) using Minitab 16 Software considering $p \leq 0.05$ as a significant difference. Tukey's test was used for comparison when there was a significant difference between data.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. Effect of Extrusion Condition and Fiber Addition on Expansion Ratio

Expansion, which is one of the first parameters coming to mind when extrusion cooking method is mentioned, is a parameter used generally in extruded snacks produced at high temperature, high pressure, and low moisture content extrusion condition (Alam et al., 2015; Patil, Berrios, Tang, & Swanson, 2007). Food materials moving in the barrel undergo some chemical and physical changes by means of the combination of the effects of pressure and temperature (Chuang & Yeh, 2004; Vanier et al., 2016). These changes like denaturation of protein, gelatinization of starch or formation of starch-lipid-protein complex provide the transformation of starchy, proteinaceous, moistened dough into viscoelastic melt structure (Mościcki & van Zuilichem, 2011; Patil et al., 2007). This melted raw material expands due to the pressure difference encountered at the outlet point of the extrusion (Moraru & Kokini, 2003; Patil et al., 2007).

Many studies have shown that the expansion of extruded products is affected by many extrusion parameters such as moisture content of the dough, screw speed, and temperature. In one of these studies, Fayose (2013) investigated the effects of moisture content (30, 40, 50 % dry basis), extrusion temperature (40, 90, 100 ºC) and screw speed (100, 150, 200 rpm) on expansion of extruded products. He found that the expansion did not change proportionally. Expansion increased up to a screw speed of 150 rpm, but decreased when the screw speed reached 200 rpm. Similarly, the expansion index, which increased up to certain dough moisture and extrusion temperature, tended to decrease in temperatures and moisture after these certain points.

Various studies have been made on the pasta or pasta-like-product related to these parameters. For example, the effects of extrusion conditions on expansion of pasta were investigated in terms of moisture content of dough or screw speed of extruder (A. Wójtowicz & Mościcki, 2009; A. Wójtowicz & Mościcki, 2014). In these studies, it was shown that as screw speed increased expansion ratio also increased while there was an opposite trend for moisture content of the dough. In another study, Giménez et al. (2013) studied the effect of extrusion temperature and moisture content of dough on gluten-free pasta quality. They used corn-broad beans, and they found that expansion increased as dough moisture decreased and extrusion temperature increased. They explained this situation by the viscosity of dough due to high extrusion temperature and moisture and elastic resistance of dough due to low extrusion temperature and moisture. Besides these studies, there is no study related to the effect of extrusion temperature on expansion of pasta produced from semolina or wheat flour. In our study, it was observed that expansion and extrusion temperature were inversely correlated. As seen in Table 3.1, expansion decreased as extrusion temperature increased in pasta produced both with and without lemon fiber (Appendix A).

Table 3.1. Expansion ratio of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	Expansion Ratio		**Expansion Ratio**
LT, ONLY SEMOLINA	$1.79 \pm 0.02^{a,A*}$	**HT, ONLY SEMOLINA**	$1.74 \pm 0.02^{a,B}$
LT, WITH FIBER	$1.69 \pm 0.01^{b,A}$	**HT, WITH FIBER**	$1.60 \pm 0.02^{b,B}$

Results are means ± standard error (n=100).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

Another finding related to this parameter is that lemon fiber addition significantly reduces the expansion of pasta produced at both low and high temperatures (Table 3.1). This was an expected result.

Hernández-Díaz, Quintero-Ramos, Barnard and Balandrán-Quintana (2007) showed that wheat bran, which is insoluble fiber, has a negative effect on expansion on the extruded product. They explained this situation by reducing effect of bran on the extensibility of cell walls, so expansion decrease. In another study, Agnieszka Wójtowicz & Mościcki (2014) explained the reducing effect of legumes (yellow pea) on expansion by the lower starch content of the raw material due to higher fiber and protein content. Another explanation for the effect of insoluble fiber on reducing expansion is the rise in shear viscosity of the melted dough in the extruder as insoluble fiber content increased may provide a higher resistance to expand at the exit point of extruder (Robin, Schuchmann, & Palzer, 2012).

3.2. Effect of Extrusion Condition and Fiber Addition on Cooking Properties

There are several methods to determine the cooking quality of pasta. Some of these methods are applied for investigating properties such as cooking loss, swelling index and water absorption index (Bustos et al., 2011; Foschia et al., 2015; Menon et al., 2012; Piwińska et al., 2016). Pasta is cooked first at optimum cooking time (OCT), and then it is analyzed for these properties. The general features of the good-quality pasta are low cooking loss and high water uptake (Bruneel et al., 2010).

3.2.1. Optimal Cooking Time (OCT)

The optimal cooking time (OCT) is an important feature in terms of both determining the quality of pasta and being a step used in determining other factors affecting pasta quality. During cooking, starch granules swell, and they tend to form a starch-protein network (Menon et al., 2012). Since gluten is also a strong component of this starch-protein network entire gluten structure is important for cooked pasta (Bruneel et al., 2010). When the white line is observed at the core of pasta, it can be said that starch is gelatinized and starch-protein network occurs; so, pasta is cooked.

Sobota and Zarzycki (2013) stated that optimal cooking time has influence over the chemical composition, nutritional value, and calories of cooked pasta. On the other hand, optimal cooking time is affected by the shape and fiber content of pasta, usage of pre-gelatinized starch in pasta formulation and extrusion temperature (Marti et al., 2013; Prabhasankar, 2013).

There are opposite results about the effect of fiber addition on the optimal cooking time of pasta. In general, lots of researches show that optimal cooking time decreases as the amount of fiber in the pasta increases (Aravind et al., 2012; Bustos et al., 2011; Martinez et al., 2012). This is explained by the dilution of gluten and formation of weaker structure by the addition of fiber to the pasta. In addition, fiber addition results in more porous structure in the pasta. These pores enable water absorption easily, and water reaches the core of pasta quickly. Thus, gelatinization of starch occurs earlier, and optimum cooking time shows a decrease. Adding fiber could not affect the optimal cooking time in some researches (Aravind et al., 2012; Piwińska et al., 2016). In these studies, addition of fiber in small quantities may not be sufficient to affect the optimum cooking time. Jayasena & Nasar-Abbas (2012)'s research supports this statement. Adding lupin flour up to 30% level (having almost 9% fiber) did not affect optimum cooking quality. More than 30% of lupin flour caused a decrease in optimum cooking time of pasta.

On the other hand, a few researches show that optimal cooking time increases as the amount of fiber in the pasta increases (Foschia et al., 2015; Sobota et al, 2015).

In our study, all type of pasta has the same optimal cooking time that is 10 min. Fiber addition or changing the extrusion temperature did not affect the cooking time significantly. Minor amount of fiber addition (5%) could not be sufficient to affect the optimum cooking time. In addition, the same optimum cooking time may be due to the fact that the pasta produced at low and high temperatures had completely gelatinized starch.

3.2.2. Cooking Loss

Cooking loss which is related to the integrity of pasta during cooking has a big importance for influencing customer acceptance (Prabhasankar, 2013). Amylose which is the component of the starch molecule is the key ingredient of cooking loss (Bustos et al., 2011). Amylose has generally linear structure while amylopectin, the other main component of starch, is in the form of highly branched. The percentage of amylose and amylopectin in starch is nearly 18-30 and 70-82, respectively (Richard et al., 2004). Amylose can act as a kind of dietary fiber because of not being easily digested as a result of forming of tight structure with mostly α-(1→4) bonds and a bit α-(1→6) bonds (Doblado-maldonado, Gomand, Goderis, & Jan, 2017). In addition, it causes turbidity of cooking water and sticky feeling in the mouth (Benhur et al., 2015). Consequently, low cooking loss is favored.

In addition, Padalino et al. (2014) said that cooking loss was related to salt soluble protein. Durum wheat semolina protein is composed of water-soluble albumins and salt soluble globulins, which are also responsible for cooking loss in pasta.

According to Turkish Food Codex Pasta Communique, the cooking loss should be less than 10 % in dry basis. Hummel (1966) said that pasta is evaluated as pretty good quality up to 6 % solid loss, good quality up to 8 % solid loss, and poor quality above 10 % solid loss.

The strong starch-protein structure allows the reduction in cooking loss (Martina Foschia et al., 2015). Cleary & Brennan (2006) stated that protein content affects this strong starch-protein structure. According to Foschia et al. (2013), type of fiber also affects this starch-protein integrity. Sissons (2008) explained, in a review, how semolina proteins (albumins, globulins, gliadin, and glutenin) lead the protein matrix. Briefly, disulphide bond (between gliadin and glutenin), hydrogen bond, and hydrophobic bond play a role in developing this matrix by linking semolina proteins with each other. Especially interaction between gliadin and glutenin, which are the main components of gluten, help cooked pasta in order to have viscoelastic structure.

However, some fragmentation in the matrix occurs during cooking; and so, some substances can pass into the cooking water. Besides, since the addition of fiber to the pasta dough may cause a deterioration in starch-protein structure, cooking loss of pasta generally increases (Cleary & Brennan, 2006). Gluten network provides amylose retention during cooking, so gluten network weakening due to fiber addition may cause increase in cooking loss (Martina Foschia et al., 2015). In addition, cooking water diffuses into the pasta unevenly, because fiber competes with other components of pasta for water hydration. This inhibits the strong starch-protein structure and causes an increase in cooking loss.

According to one-way ANOVA results, there is no significant difference between pasta prepared with and without fiber for both extrusion conditions. (Table 3.2).

Table 3.2. Cooking loss of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	Cooking Loss (%)		**Cooking Loss (%)**
LT, ONLY SEMOLINA	$7.51 \pm 0.67^{a,A*}$	**HT, ONLY SEMOLINA**	$6.70 \pm 0.51^{a,A}$
LT, WITH FIBER	$9.65 \pm 0.43^{a,A}$	**HT, WITH FIBER**	$8.87 \pm 0.67^{a,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different ($p \leq 0.05$).

Padalino et al. (2014) added pea flour (15%) to the durum wheat spaghetti. In that research, adding pea flour, which contains a high amount of insoluble dietary fiber as lemon fiber, to durum wheat semolina caused a significant increase in cooking loss. The addition of pea flour causes a reduction in gluten ratio and weakens protein structure. Because of this weakened protein structure more solid from pasta can pass to the cooking water.

In another research, buckwheat flour and wheat bran, which were also high in insoluble fiber, were used in pasta (Chillo et al., 2008). Buckwheat flour (up to 30%) and wheat bran (up to 20%) were added at different percentages. According to the results, the spaghetti, which had less than 15% wheat bran, was acceptable in terms of some quality parameters. Cooking loss of this acceptable spaghetti had no significant difference with spaghetti prepared using only durum wheat semolina. However, a significant difference was observed when more than 15% of wheat bran was added.

Following the search, it can be said that the effect of fiber addition changes according to type and amount of fiber. In our study, the amount of lemon fiber added to pasta may not be high enough to affect the cooking loss (Table 3.2).

Besides the effect of fiber addition, extrusion conditions, which is different barrel temperatures in this study, can also affect the cooking loss of pasta during cooking process. Pasta made at high temperature conditions. have less soluble and more connected structure (Giménez et al., 2013). In their experiment, three different temperatures were set in the single screw extruder: 80, 90 and 100ºC. They observed that amount of solid pass to the cooking water showed decrease as extrusion temperature increases. This was most probably related to more rigid body due to extrusion process. A more rigid body enabled less soluble structure, so cooking loss decrease.

In contrast to the results obtained by Giménez et al. (2013) in our study, there was no significant difference between cooking loss values of pasta produced at different extrusion temperatures (Table 3.2). Extrusion temperatures used in this research allows the cooking loss values to remain within the acceptable range according to Turkish Food Codex Pasta Communique (Tarım ve Köy İşleri Bakanlığı, 2002a).

3.2.3. Swelling Index

The swelling index is one of the most important parameters used to determine the hydration and cooking properties of pasta. It shows the mass ratio of water to solid in the cooked pasta. As it is known, there are two important events in the pasta during cooking: starch gelatinization and protein coagulation (Sicignano et al., 2015). Gluten, starch, and fiber, if there is, which are the most important components of pasta acting a role in these events need water in order to constitute strong structure. So, it can be said that they compete for using the water in the surrounding (De Pilli et al., 2013). Starch is in tendency to form a semi-crystalline structure when sufficient temperature is provided and enough water is available (R. F. Tester & Sommerville, 2003). This process is called gelatinization. While starch granules tend to swell by using water in their surroundings during gelatinization, the gluten network is able to inhibit this willing, it means that there is an antagonistic situation (Ogawa et al., 2014). The effects of extrusion temperature and fiber addition on swelling index of pasta can be seen in Table 3.3.

Table 3.3. Swelling index of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	Swelling Index (g water/g dry pasta)		**Swelling Index (g water/g dry pasta)**
LT, ONLY SEMOLINA	$1.50 \pm 0.04^{a,B*}$	**HT, ONLY SEMOLINA**	$1.75 \pm 0.04^{b,A}$
LT, WITH FIBER	$1.57 \pm 0.02^{a,B}$	**HT, WITH FIBER**	$2.08 \pm 0.07^{a,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different ($p \leq 0.05$).

One-way ANOVA results show that 5 % lemon fiber addition has no significant effect on the swelling index values of pasta when produced at low extrusion temperature. However, pasta with fiber has a significantly higher swelling index than pasta prepared with only semolina at high temperature (Table 3.3).

In literature, there are different results about the effect of fiber content on the swelling index of pasta. Some of them indicate that adding fiber decreases the swelling index of pasta (Bustos et al., 2011). The other ones show that either no significant difference (Tudorică et al., 2002) or an increase in swelling index (Foschia et al., 2015; Piwinska et al., 2015) with the addition of fiber.

Tudorică et al. (2002) used pea and inulin fiber, which are mainly insoluble, at 7.5, 10, 12.5 and 15% concentrations. Although they slightly increase the swelling index of pasta, there was no difference statistically. This could be explained by the insufficient capacity of these fibers to absorb and retain water. In another research, Piwinska et al. (2015) used oat powder, which contains 78% insoluble fiber, in order to observe hydration properties of durum wheat semolina pasta. They observed that increasing amount of fiber increased the swelling index of pasta. They explained that fiber could absorb more water during cooking than durum wheat semolina. It could also be said that higher water holding capacity enables more swelling power.

Yildiz et al. (2013) stated that swelling property of starch is mainly related to amylopectin content. The addition of water insoluble dietary fiber could cause a deterioration in the integrity of amylopectin structure, which means less strong starch matrix. In other words, starch granules can easily disintegrate during heating, and the amount of amylopectin released to the system shows a rise. Thus, it can be said that starch matrix has more porous structure, which provides an increase in swelling index. This could also be the reason for having significantly higher swelling index of pasta produced at high temperature.

According to one-way ANOVA results for the swelling index of pasta produced with only semolina, there is a significant difference between low and high temperature conditions (Table 3.3). Similarly, the difference between the swelling index of pasta with fiber produced at low temperature and high temperature were statistically significant. According to Giménez et al. (2013) high temperature extrusion condition enable a more homogenous starch structure which provides higher swelling index. Alam et al. (2015) claim that mechanical force related to shearing is high at high temperature. Macromolecular disruption, which is explained by disintegration of the quaternary and tertiary structure of food material, occurs because of these large shearing forces in the extruder. This degradation of food affects some functional properties of food like swelling index, water absorption.

3.2.4. Water Absorption

The water absorption index is used as an indicator for observing stability of starch network (Giménez et al., 2013). Besides, it shows that how much water that pasta can absorb during cooking. Sobota et al. (2015) stated that foods having high water absorption capacity give a feeling of fullness since they swell in stomach and provide reducing feeling of hunger.

In this study, pasta produced with only semolina at low temperature (LT) had the lowest water absorption index while the highest water absorption index was observed in pasta with fiber produced at high temperature (Table 3.4.).

Table 3.4. Water absorption index of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	Water Absorption Index (%)		**Water Absorption Index (%)**
LT, ONLY SEMOLINA	$112.32 \pm 0.68^{b,B*}$	**HT, ONLY SEMOLINA**	$127.25 \pm 0.54^{b,A}$
LT, WITH FIBER	$128.48 \pm 4.47^{a,B}$	**HT, WITH FIBER**	$147.94 \pm 2.48^{a,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

It is known that one of the most important factors affecting the water absorption index is the cooking time (Martinez et al., 2012; Sobota & Zarzycki, 2013). This index is determined by cooking pasta up to optimum cooking time. Higher optimum cooking time provides higher water absorption. For example, in the study of Martinez et al. (2012) amaranth flour was added to pasta in order to observe its effects on quality of pasta. Addition of amaranth caused a decrease in optimum cooking time of pasta. This affected the water absorption of pasta; in a sense, it also showed a decrease. However, since pasta worked on in our study has the same optimum cooking time, it can be said that this property has no effect on water absorption index.

Addition of lemon fiber to the pasta produced at both low temperature and high temperature significantly increased the water absorption index (Table 3.4). Bustos et al. (2011) used two types of resistant starches and inulin in order to increase the functionality of pasta. These fibers caused a decrease in the water absorption index of the pasta. The low water holding capacities of these fibers were considered as the reason for this decrease. On the other hand, addition of wheat bran caused an increase in water absorption (Sobota et al., 2015). Wheat bran had higher water absorption capacity than semolina, almost more than twice. Thus, pasta with wheat bran had more water absorption capacity. In our study, since lemon fiber has high water holding capacity, an increase in water absorption index with fiber addition into the pasta is an expected result.

Similar results were observed by Piwińska et al. (2016). In this study, it was aimed to determine how oat β-glucan fiber powder affects cooking quality and physical properties of pasta. The increase in water absorption was explained by the fact that the hydroxyl groups in the fibers were higher than those of the semolina. Thus, fiber had greater interaction with water due to hydrogen bonds. In addition, deterioration of protein structure due to fiber addition may have resulted in an increase in water absorption (De Pilli et al., 2013).

According to one-way ANOVA results for water absorption index of pasta produced with only semolina, there was a significant difference between low and high extrusion temperature conditions (Table 3.4). Similarly, the difference between the water absorption index of pasta with fiber produced at low and high temperature was statistically significant.

3.3. Effect of Extrusion Condition and Fiber Addition on Rehydration Rate

Drying is one of the most important ways of food preservation (Ogawa et al., 2011). Similar to some vegetables, fruits or other foodstuffs, pasta is usually dried in order to promote effective storage duration and provide stability of product during transportation by decreasing moisture content. Then, it needs to be rehydrated before consumption.

Three mechanisms play an important role in the rehydration process: starch gelatinization, relaxation of gluten network and water diffusion (Ogawa & Adachi, 2014; Ogawa et al., 2014). According to Ogawa and Adachi (2014), there are some holes and cracks on the surface of pasta, and at first, water only fills these holes and cracks. Water diffusion exists from the surface to the inner part of pasta due to the concentration gradient. Since starch gelatinization is a quick process, it occurs in the presence of water and heat in a few minutes. At the same time, rehydration of gluten also occurs and the gluten matrix that had shrunk during drying process can relax in the presence of water.

In this study, pasta was weighed at 2 min intervals up to 20 min during rehydration. Using the weight of uncooked pasta (W_u) and weight of cooked pasta at various cooking time (W_i), rehydration rate was calculated. It was supposed that a higher slope of W_i/W_u vs. time graph showed quicker rehydration.

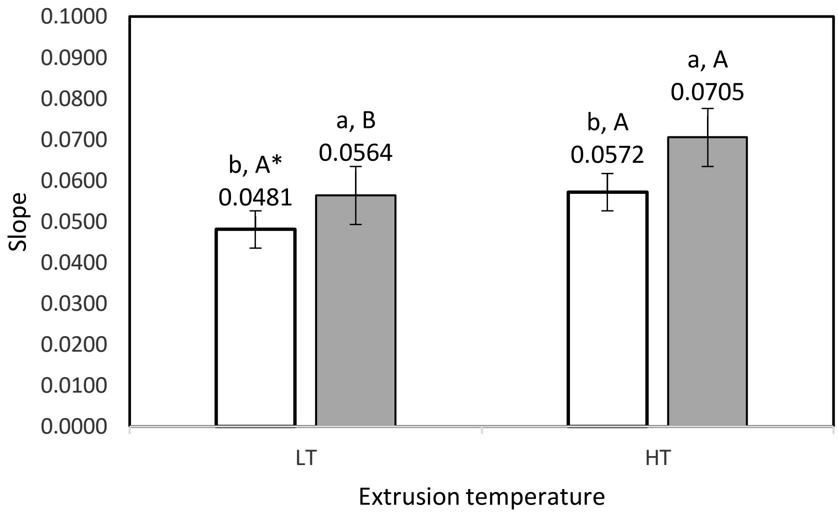

Figure 3.1. Slope of W_i/W_u vs. time graph for comparison of rehydration rate of pasta with only semolina (□) and with fiber addition (■) producing at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85-70°C).

*Results are means ± standard error (n=2). Bars in the LT area with different small letters and bars in the HT area with different small letters represent significantly different results between pasta produced with and without fiber ($p \leq 0.05$). Empty bars with different capital letters and solid bars with different capital letters represent significantly different results between pasta produced at low and high extrusion temperature ($p \leq 0.05$).

Addition of lemon fiber increased the rehydration rate of pasta produced at both low and high temperatures significantly (Figure 3.1). This may be explained by the high water holding capacity of lemon fiber. In addition, fiber affects gluten-starch matrix adversely, and it results in a more porous structure in the pasta. This porous structure can absorb water easily. Another found result was that extrusion temperature was significantly more effective when adding lemon fiber to the pasta. It was observed that the rehydration rate increased as the extrusion temperature increased in the pasta with the addition of lemon fiber.

3.4. Effect of Extrusion Condition and Fiber Addition on Gelatinization Degree

Starch has two main components: amylose which is generally in the amorphous and semi-crystalline region and amylopectin which is located in the crystalline region.

Starch gelatinization is one of the most important processes for cooked pasta. Schirmer et al. (2015) stated that some changes are observed in starch when it is exposed to heat in the presence of water. The changes are glass transition, gelatinization, and forming of amylose-lipid complex. At glass transition state, starch granules changes from glassy state to rubbery state by absorbing water. These structural changes provide the hydration and breakage of double helices in the starch structure. This breakage occurring after the glass transition temperature is called gelatinization. In other words, gelatinization is an irreversible process that causes destruction of starch molecules with specific amount of water and heat.

Starch gelatinization is affected by chemical structure, pasting properties, water binding capacity, starch damage etc. (Vansteelandt & Delcour, 1998). Starch damage is due to some process like mixing, drying and extrusion. As it is known, extrusion process is the most important stage to produce pasta. Wojtowicz (2005) said that there were some factors that affect the gelatinization of starch during extrusion process. These were temperature/shearing interactions, moisture content of dough and screw speed. An increase in these factors facilitated starch gelatinization. Similarly, Wójtowicz and Mościcki (2009) showed in their study that higher gelatinization degree had been observed when the moisture content of dough (32%) and the screw speed (120 rpm) were the highest.

In this study, moisture content of dough and screw speed was kept constant. However, two different extrusion temperatures were applied in order to observe the effect of temperature on pasta quality. Semolina itself and all types of pasta were analyzed in DSC in order to calculate gelatinization degree of pasta. The gelatinization enthalpy of semolina was 6.1009 J/g where onset temperature (T_o) was 54.46ºC, endset temperature (T_e) was 67.05ºC and peak temperature (Tp) was 60.74 ºC (Appendix B). However, there was no peak in DSC thermograms for all types of pasta produced with and without fiber at different extrusion temperatures. This means that starch in the pasta was completely gelatinized during extrusion process. That is, extrusion process conditions (30% moisture content of dough, 200 rpm, 15 ± 1 g/min feed flow rate) was sufficient for starch gelatinization. Fiber addition was expected to retard gelatinization due to competition with water. However, 5% lemon fiber could not be at the level that prevents starch to gelatinize.

3.5. Effect of Extrusion Condition and Fiber Addition on Color

The bright yellow color in pasta is an important parameter for consumer acceptance. Especially carotenoid pigments are responsible for the yellow color of pasta (Piwińska et al., 2016). Ash content of semolina also plays a role in coloring. Higher ash content causes faint color in pasta (Brennan & Zealand, 2013). Thus, it can be said that the intrinsic property of semolina is effective in the color of pasta. Color is generally expressed as L^*, a^* and b^* values where L^* value indicates lightness (brightness), a^* value indicates redness and b^* value indicates yellowness. Semolina used in this study has 87.05 L^* value, 1.54 a^* value and 19.92 b^* value. Lemon fiber used in this study has 79.98 L^* value, 0.17 a^* value and 9.75 b^* value. It can be said from these results that the color of the semolina is brighter and yellower than the color of the semolina-lemon fiber mixture.

While addition of lemon fiber significantly decreased the L^* value of pasta, extrusion temperature could not change this value at a significant level (Table 3.5). Being darker pasta when lemon fiber is added can be explained by the intrinsic property of lemon fiber since lemon fiber has less bright color than semolina. Similar results were observed in the study of Bustos et al. (2011). They used resistant starch and inulin fiber, which are white in color, for fortification of pasta. Fiber enriched pasta have higher L^* values than control. Although the yellow color of pasta is often important for consumers (Lucia Padalino et al., 2014), some sensory research (Sobota et al., 2015) shows that consumers prefer darker pasta because they think they are healthy because they contain fiber.

Table 3.5. L^* values of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	L^*		L^*
LT, ONLY SEMOLINA	$51.99 \pm 0.18^{a,A*}$	**HT, ONLY SEMOLINA**	$52.56 \pm 0.17^{a,A}$
LT, WITH FIBER	$48.46 \pm 0.21^{b,A}$	**HT, WITH FIBER**	$48.76 \pm 0.16^{b,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

One-way ANOVA results for b^* values of pasta shows similarity with L^* value (Table 3.5). The reason for this result can be explained by the same reason. Since b^* value of lemon fiber is lower than semolina, pasta with fiber has lower yellow color.

Table 3.6. b^* values of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	b^*		b^*
LT, ONLY SEMOLINA	$19.69 \pm 0.30^{a,A*}$	**HT, ONLY SEMOLINA**	$20.75 \pm 0.24^{a,A}$
LT, WITH FIBER	$15.27 \pm 0.14^{b,A}$	**HT, WITH FIBER**	$14.92 \pm 0.14^{b,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

According to Bustos et al. (2011), L^* and b^* values are more important than a^* value in the case of pasta. A similar conclusion can be made in this study. Both fiber addition and extrusion temperature showed no significant difference in a^* values of pasta (Table 3.7). However, when the comparison between before and after extrusion process was done, an increase in a^* value can be observed. As mentioned in the first paragraph, semolina used in this study has 1.54 a* value while lemon fiber used in this study has 0.17 a* value. After extrusion process, a* value of pasta reached a value of around 3. A similar increase was also observed in most of the researches (Bustos et al., 2011; Piwińska et al., 2016) . This increase was explained by Maillard reaction in all of these researches. In Maillard reaction, amino acid and reducing sugar reacted at high temperature, and thus melanoidins that gave the brown-reddish color to pasta were formed. In this study, both low and high temperature extrusion conditions could provide similar increase in a^* value. The reason for insignificant effect of fiber addition on a* value may be its similar a* value with the semolina and its low concentration (5%).

Table 3.7. a^* values of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	a^*		**a^***
LT, ONLY SEMOLINA	$3.37 \pm 0.17^{a,A*}$	**HT, ONLY SEMOLINA**	$2.96 \pm 0.12^{a,A}$
LT, WITH FIBER	$3.02 \pm 0.04^{a,A}$	**HT, WITH FIBER**	$2.85 \pm 0.15^{a,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

3.6. Effect of Extrusion Condition and Fiber Addition on Textural Properties

Textural properties of pasta show how pasta can protect its structure during cooking. Foschia et al. (2015) explained that the textural properties of pasta are developed with the help of mainly starch and protein, which are the main components of raw material. During cooking, proteins hydrate and coagulate while swelling and gelatinization of starch occurs; at the end, the formation of protein-starch matrix takes place. Since these two mechanisms occur at the same conditions, which are temperature and humidity, they compete for the water. If protein coagulation predominates, starch molecules are embedded into the gluten network, which forms as honeycomb; thus, pasta firmness is promoted. Otherwise, if swelling of starch predominates, proteins coagulate fragmentary; thus, pasta becomes softer. In the light of this information, it can be said that the development of protein network has a critical role in obtaining pasta with acceptable textural properties (Bustos et al., 2015).

One of the parameters which give information about the textural properties of pasta is firmness. Firmness of pasta is the highest cutting force of compression which simulates the teeth force during chewing. Firmness values observed in this study are given Table 3.8.

Table 3.8. Firmness of pasta with and without fiber addition and produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85°C-70°C)

	Firmness (g.cm)		**Firmness (g.cm)**
LT, ONLY SEMOLINA	$6.57 \pm 0.27^{a,A*}$	**HT, ONLY SEMOLINA**	$5.62 \pm 0.35^{a,A}$
LT, WITH FIBER	$5.71 \pm 0.18^{a,A}$	**HT, WITH FIBER**	$4.73 \pm 0.37^{a,A}$

Results are means ± standard error (n=3).

*Mean values with the same small letters in the same column and with the same capital letters in the same row are not significantly different (p≤0.05).

As can be seen from Table 3.8, there is no significant difference between the firmness of pasta with lemon fiber at both low and high extrusion temperatures. This result has similarity with some researches in literature. Tudorică et al. (2002) used pea and inulin fiber at 7.5, 10, 12.5 and 15% concentrations in order to observe how they affect the physicochemical and nutritional characteristics of pasta. Inulin addition at these concentrations could not affect the firmness significantly. Besides, while pea fiber addition at 10 and 12.5% concentrations could not affect the firmness significantly, pasta with 7.5 and 15% pea fiber had significant decrease in firmness. The reason for reduction trend in firmness could be weak protein-starch network due to fiber addition. Fiber addition had destructive effect on protein structure; thus, the weakened protein matrix allowed starch to take up more water. This caused pasta to be softer.

Piwińska et al. (2016) used oat β-glucan for the fortification of pasta and observed decrease in the firmness. This was explained by higher water absorption of pasta with oat β-glucan fiber than control. It enabled pasta with higher moisture when cooked. In our study, it was expected that the lemon fiber could have similar effect on pasta firmness due to the same reason. Lemon fiber addition was found to increase water absorption. The second reason for this expectation was physical deterioration of protein matrix with the addition of non-gluten substance, which was lemon fiber in our study. On the other hand, De Pilli et al. (2013) explained the reason for the decline in hardness of pasta by the poor availability of water required for the protein matrix since this water was bound to the fiber. On the other hand, according to Bruneel et al. (2010), good texture of the pasta is explained by high firmness. In our study, addition of lemon fiber was not enough to negatively influence pasta texture (Table 3.8). The addition of lemon fiber at higher doses (more than 5%) may have adverse effect on pasta texture.

When the effect of extrusion temperature on pasta texture was examined, no significant difference was observed in firmness of both pasta produced with fiber and with only semolina. Wójtowicz & Mościcki (2009) also worked on extrusion cooking parameters. They saw that firmness increased as gelatinization degree, which was related to high extrusion temperature, increased. In our study, starch was completely gelatinized in all types of pasta. So, one reason for observing no difference could be explained by complete gelatinization in all cases. In addition, Wójtowicz & Mościcki (2009) found a negative correlation between firmness and hydration time. Longer hydration time caused decrease in firmness due to higher water absorption. In our study, firmness may not be significantly different since pasta produced at both low and high temperature had the same optimum cooking time, in other words they were hydrated for the same time.

3.7. Effect of Extrusion Condition and Fiber Addition on Microstructure

Microstructure of all types of pasta was analyzed by using Scanning electron microscopy (SEM) and it was used for observing the effect of lemon fiber addition and extrusion temperature on the starch-protein matrix in pasta. SEM images of cross section and surface section of uncooked pasta were given in Figure 3.2 and Figure 3.3, respectively. All of the images were taken at 1500× magnification.

As can be seen in Figure 3.2, SEM images of cross section of all pasta with lemon fiber showed a more disorganized and uneven structure. This result may be due to the adverse effect of addition of fiber on the protein-starch network. Similar results can be found in literature (Aravind et al., 2012; Rekha et al., 2013; Wójtowicz & Mościcki, 2014). The results of other analyses that were done for determining the pasta quality like cooking properties and textural measurements were consistent with these microstructural results. As explained earlier, in this study, swelling index and water absorption index of fiber-enriched pasta increased due to the deterioration of protein-starch structures, which is the result of fiber addition. Besides, discontinuity in the gluten network was observed (Figure 3.2B and Figure 3.2D).

Similar to the results of the degree of gelatinization, it can be said that starch is completely gelatinized according to SEM images. The structure of starch is dispersed.

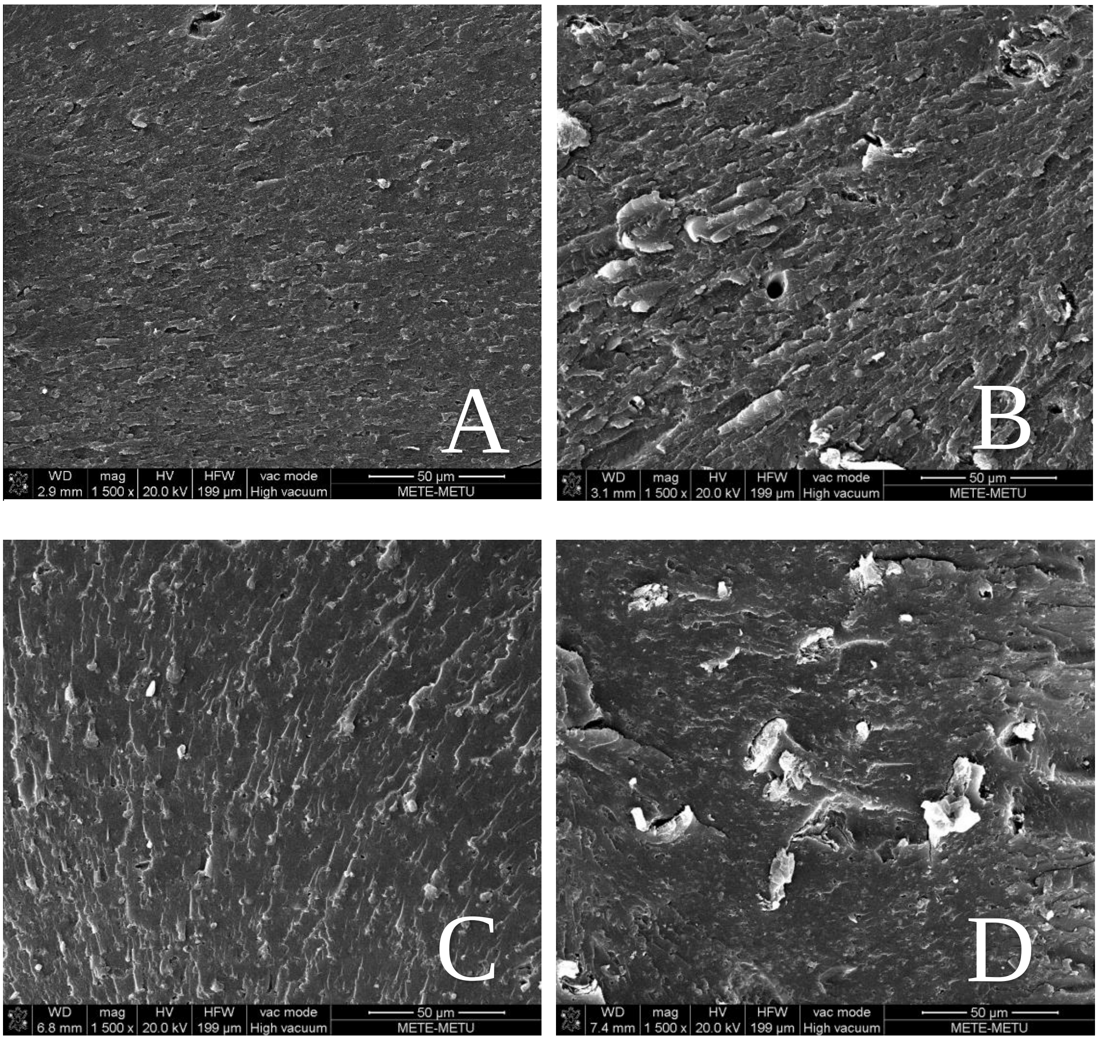

Figure 3.2. SEM images of cross section of uncooked pasta. A: pasta with only semolina produced at low temperature B: pasta with lemon fiber produced at low temperature C: pasta with only semolina produced at high temperature D: pasta with lemon fiber produced at high temperature

Fiber addition also affected the surface structure of pasta (Figure 3.3). Fiber enriched pasta had a rougher and more undulating surface. Small-gelatinized starch granules on the surfaces of pasta could be seen more easily. Wójtowicz & Mościcki (2014) also observed a similar picture for pasta with legume flour. They also observed that roughness of pasta increased as increasing amount of legume flour. In addition, it may be said that pasta produced at higher temperature could have more consolidated structure (Figure 3.3C-D), as also observed by Wójtowicz & Mościcki (2009).

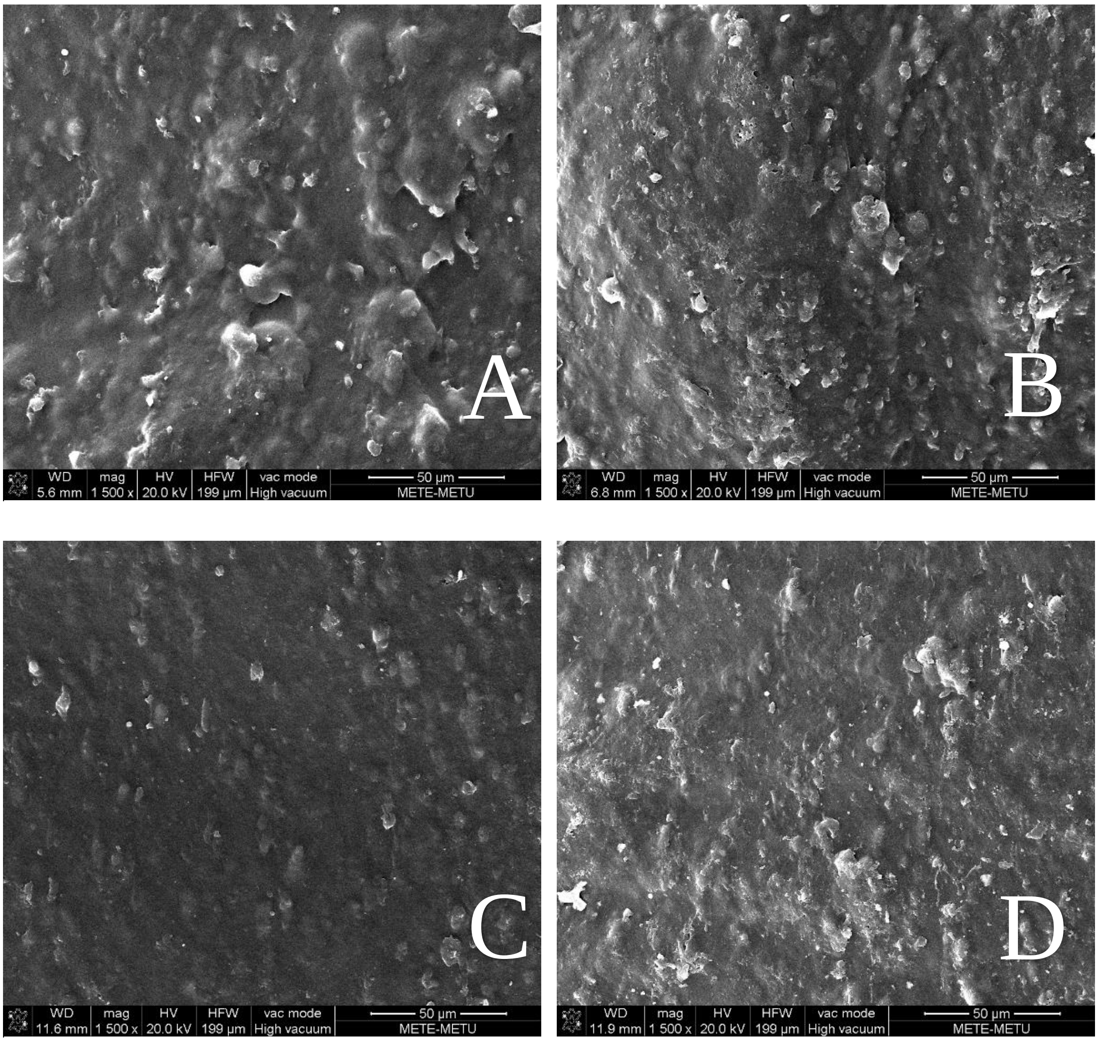

Figure 3.3. SEM images of surface section of uncooked pasta A: pasta with only semolina produced at low temperature B: pasta with lemon fiber produced at low temperature C: pasta with only semolina produced at high temperature D: pasta with lemon fiber produced at high temperature

3.8. Effect of Extrusion Condition and Fiber Addition on Dietary Fiber Content

It was found that lemon fiber, used in this study, had 82.79% total dietary fiber of which soluble part was 19.38% and insoluble part was 63.41% by using AACC Method 32-07. In addition, total/insoluble/soluble fiber content of raw material which consisted of semolina and 5% of lemon fiber and pasta produced at low and high temperature was also determined (Table 3.9).

According to these results, insoluble dietary fiber of pasta produced both at low and high temperature was almost the same as that of the raw material. Similarly, when analyzed in terms of the amount of soluble and total dietary fiber, there was no significant difference between raw material and pasta produced at different temperature conditions (Table 3.9).

Table 3.9. Percentage of total dietary fiber (TDF), insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) contents in all ingredients of raw material and pasta produced at different temperatures (LT: 40°C-40°C-65°C-45°C, HT: 65°C-65°C-85-70°)

	%TDF	**%IDF**	**%SDF**
Semolina+Fiber Mixture	$9.13 \pm 0.14^{a*}$	6.12 ± 0.10^{a}	3.01 ± 0.18^{a}
Pasta produced at LT	9.11 ± 0.17^{a}	6.13 ± 0.02^{a}	2.98 ± 0.16^{a}
Pasta produced at HT	9.44 ± 0.03^{a}	6.17 ± 0.10^{a}	3.27 ± 0.13^{a}

Results are means ± standard error (n=2).

*Mean values with the same small letters in the same column are not significantly different ($p \leq 0.05$).

There are some studies in literature in which the influence of the extrusion process on dietary fiber content is searched (Alam et al., 2015; Giménez et al., 2013; Méndez-García et al., 2011; L. Wang et al., 2016). These studies showed that as extrusion temperature increased, greater physical stress was generated. In other words, the pressure in the extruder barrel increased by increasing temperature. The higher pressure provided the breakdown of glycosidic bonds in polysaccharides. This enabled the oligosaccharides to be free and caused a decrease in the amount of insoluble fiber and increase in the amount of soluble fiber.

The temperature values and screw speed used in our study may not provide the required pressure to change the structure of the fibers.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In this study, the effects of fiber content and extrusion conditions on the quality of pasta were evaluated. Pasta was made at two different temperature profiles (40°C, 40°C, 65°C, 45°C (Die: 55°C) and 65°C, 65°C, 85°C, 70°C (Die: 80°C)) in the extruder using durum wheat semolina both without fiber addition and 5% lemon fiber addition. Parameters evaluated in this study were optimal cooking time, cooking loss, swelling index, water absorption index, rehydration rate for cooked pasta; expansion ratio, gelatinization degree, color, firmness and microstructural properties for uncooked pasta and dietary fiber content for raw and dried extruded pasta.

In this study, it was shown that lemon fiber addition significantly reduced the expansion ratio of pasta produced at both low and high temperature extrusion conditions. Besides, it was also found that the extrusion temperature was inversely proportional to the expansion ratio of pasta.

The results related to the cooking properties showed that fiber addition and pasta production at different temperatures had no effect on cooking time. The optimum cooking time of all pasta samples was found to be 10 min. For cooking loss, it was seen that there is no significant difference between pasta prepared with and without lemon fiber for both extrusion conditions. Another cooking property, the swelling index, tended to increase as the extrusion temperature increased independent of the components of the pasta. On the other hand, it was observed that the swelling index increased when lemon fiber was added to the pasta produced at high temperature, while the addition of lemon fiber had no effect on the swelling index in the pasta produced at low temperature. When water absorption index, which is the last cooking property, examined, it was observed that the addition of lemon fiber increased the water absorption index independent of the extrusion temperature. Similarly, it was also found that extrusion temperatures had significant effect on the water absorption index. As extrusion temperature increased, water absorption index also increased.

When the rehydration rate results were examined, the extrusion temperature was found to be more effective when lemon fiber was added to the pasta. It was observed that the rate of rehydration increased as the extrusion temperature increased in the pasta with the addition of lemon fiber. Besides, addition of lemon fiber increased the rehydration rate of pasta produced at low and high temperatures significantly.

It was found that all extrusion temperatures were sufficient to complete starch gelatinization. In addition, it was observed that the amount of lemon fiber added was not sufficient to affect gelatinization.

Addition of lemon fiber caused significantly darker (related to L* value) and less yellowish (related to b* value) pasta in all cases. However, it was found that extrusion temperatures had no effect on the color of pasta in terms of L* and b* value. In addition, considering the a* values of the raw materials used, it was seen that the extrusion process increased the a* value in all the pasta produced in this study.

According to the results of texture analyzes, the addition of lemon fiber or changing extrusion temperature profiles had no significant effect on firmness value of pasta.

SEM images of cross section of all pasta with lemon fiber showed a more disorganized and uneven structure. On the other hand, according to SEM images of surface structure, fiber enriched pasta had a rougher and more undulating surface. In addition to these, it may be said that pasta produced at higher temperature could have a more consolidated structure.

Results indicated that extrusion temperature conditions did not affect the soluble-insoluble fiber ratio of pasta.

In conclusion, the addition of 5% lemon fiber to the pasta was found to have an acceptable effect on pasta quality in general. First, the addition of lemon fiber did not adversely affect the cooking loss. Besides, it provides higher water absorption, swelling index, and rehydration rate. The textural properties were not significantly affected by lemon fiber fortification. The extrusion temperatures used in the study did not affect the quality of the pasta, nor did it affect the cooking time or fiber content.

As a future work, different types of ingredients (different type of flour), different screw configuration, different moisture content of dough, different screw speed or different die combination may be used in order to produce pasta having less optimum cooking time. In addition, higher concentrations of lemon fiber may be studied to find out how many percent of lemon fiber could be added without affecting the quality of pasta adversely. In the end, all of these studies may be supported by sensorial analysis.

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APPENDICES

A. STATISTICAL ANALYSIS

Table A. 1 One-way ANOVA and Tukey's Comparison Test for expansion ratio of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                       DF        SS        MS       F      P
Extrusion temperature         1  0,137288  0,137288  323,82  0,000
Error                       198  0,083944  0,000424
Total                       199  0,221232

S = 0,02059   R-Sq = 62,06%   R-Sq(adj) = 61,86%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  -------+---------+---------+---------+--
HT     100  1,7366  0,0179  (-*--)
LT     100  1,7890  0,0229                                 (-*--)
                            -------+---------+---------+---------+--
                                1,744     1,760     1,776     1,792

Pooled StDev = 0,0206


Grouping Information Using Tukey Method

C1    N     Mean  Grouping
LT  100  1,78900  A
HT  100  1,73660    B

Means that do not share a letter are significantly different.
```

Table A. 2 One-way ANOVA and Tukey's Comparison Test for expansion ratio of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                        DF        SS        MS        F      P
Extrusion temperature          1  0,428738  0,428738  1897,41  0,000
Error                        198  0,044740  0,000226
Total                        199  0,473478

S = 0,01503   R-Sq = 90,55%   R-Sq(adj) = 90,50%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev   -+---------+---------+---------+--------
HT     100  1,6006  0,0160   (*)
LT     100  1,6932  0,0140                                      (*)
                             -+---------+---------+---------+--------
                            1,600     1,625     1,650     1,675

Pooled StDev = 0,0150

Grouping Information Using Tukey Method

Extrusion temperature    N     Mean  Grouping
LT                     100  1,69320  A
HT                     100  1,60060    B

Means that do not share a letter are significantly different.
```

Table A. 3 One-way ANOVA and Tukey's Comparison Test for expansion ratio of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source             DF        SS        MS        F      P
Ram material        1  0,458882  0,458882  1271,18  0,000
Error             198  0,071476  0,000361
Total             199  0,530358

S = 0,01900   R-Sq = 86,52%   R-Sq(adj) = 86,46%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  -------+---------+---------+---------+--
Fiber  100  1,6932  0,0140  (*-)
Sem    100  1,7890  0,0229                                 (*-)
                            -------+---------+---------+---------+--
                                 1,710     1,740     1,770     1,800
Pooled StDev = 0,0190

Grouping Information Using Tukey Method

C7       N     Mean  Grouping
Sem    100  1,78900  A
Fiber  100  1,69320    B
Means that do not share a letter are significantly different.
```

Table A. 4 One-way ANOVA and Tukey's Comparison Test for expansion ratio of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source           DF        SS        MS        F      P
Raw material      1  0,924800  0,924800  3200,78  0,000
Error           198  0,057208  0,000289
Total           199  0,982008

S = 0,01700   R-Sq = 94,17%   R-Sq(adj) = 94,14%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev   -+---------+---------+---------+--------
Fiber  100  1,6006  0,0160   (*)
Sem    100  1,7366  0,0179                                     (*)
                             -+---------+---------+---------+--------
                            1,600     1,640     1,680     1,720
Pooled StDev = 0,0170

Grouping Information Using Tukey Method

Raw materail      N     Mean  Grouping
Sem             100  1,73660  A
Fiber           100  1,60060    B

Means that do not share a letter are significantly different.
```

Table A. 5 One-way ANOVA and Tukey's Comparison Test for cooking loss of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Semolina versus Extrusion temperature

```
Source                    DF    SS    MS     F      P
Extrusion Temperature      1  0,98  0,98  0,92  0,391
Error                      4  4,25  1,06
Total                      5  5,23
S = 1,030   R-Sq = 18,78%   R-Sq(adj) = 0,00%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level  N   Mean  StDev  --------+---------+---------+---------+-
HT     3  6,697  0,873  (-------------*-------------)
LT     3  7,506  1,167         (-------------*------------)
                        --------+---------+---------+---------+-
                              6,0       7,2       8,4       9,6

Pooled StDev = 1,030

Grouping Information Using Tukey Method

Extrusion Temperature    N   Mean  Grouping
LT                       3  7,506  A
HT                       3  6,697  A
Means that do not share a letter are significantly different.
```

Table A. 6 One-way ANOVA and Tukey's Comparison Test for cooking loss of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source  DF     SS     MS     F      P
C10      1  0,903  0,903  0,96  0,383
Error    4  3,773  0,943
Total    5  4,677
S = 0,9713   R-Sq = 19,32%   R-Sq(adj) = 0,00%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level  N   Mean  StDev  -------+---------+---------+---------+--
HT     3  8,873  1,157  (---------------*--------------)
LT     3  9,649  0,740          (--------------*---------------)
                        -------+---------+---------+---------+--
                             8,0       9,0      10,0      11,0

Pooled StDev = 0,971

Grouping Information Using Tukey Method

Extrusion Temperature  N    Mean  Grouping
LT                     3  9,6488  A
HT                     3  8,8727  A

Means that do not share a letter are significantly different.
```

Table A. 7 One-way ANOVA and Tukey's Comparison Test for cooking loss of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF      SS     MS     F      P
Raw material   1   6,887  6,887  7,21  0,055
Error          4   3,819  0,955
Total          5  10,706
S = 0,9771   R-Sq = 64,33%   R-Sq(adj) = 55,41%

                        Individual 95% CIs For Mean Based on Pooled StDev
Level  N   Mean  StDev    +---------+---------+---------+---------
Fiber  3  9,649  0,740                  (---------*----------)
Sem    3  7,506  1,167    (---------*---------)
                          +---------+---------+---------+---------
                        6,0       7,5       9,0      10,5

Pooled StDev = 0,977


Grouping Information Using Tukey Method

Raw material    N    Mean  Grouping
Fiber           3  9,6488  A
Sem             3  7,5061  A

Means that do not share a letter are significantly different.
```

Table A. 8 One-way ANOVA and Tukey's Comparison Test for cooking loss of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF     SS    MS     F      P
Raw materail  1   7,10  7,10  6,76  0,060
Error         4   4,20  1,05
Total         5  11,30
S = 1,025   R-Sq = 62,82%   R-Sq(adj) = 53,53%

                        Individual 95% CIs For Mean Based on
                        Pooled StDev
Level  N   Mean  StDev  ------+---------+---------+---------+---
Fiber  3  8,873  1,157              (----------*----------)
Sem    3  6,697  0,873  (----------*----------)
                        ------+---------+---------+---------+---
                            6,0       7,5       9,0      10,5

Pooled StDev = 1,025

Grouping Information Using Tukey Method

Raw material    N   Mean  Grouping
Fiber           3  8,873  A
Sem             3  6,697  A

Means that do not share a letter are significantly different.
```

Table A. 9 One-way ANOVA and Tukey's Comparison Test for swelling index of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                    DF       SS       MS      F      P
Extrusion temperature      1  0,09010  0,09010  19,14  0,012
Error                     4  0,01883  0,00471
Total                     5  0,10893
S = 0,06861   R-Sq = 82,71%   R-Sq(adj) = 78,39%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ----+---------+---------+---------+-----
HT     3  1,7512  0,0652                     (--------*--------)
LT     3  1,5061  0,0718  (---------*--------)
                          ----+---------+---------+---------+-----
                            1,44      1,56      1,68      1,80

Pooled StDev = 0,0686

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  1,75119  A
LT                     3  1,50611    B

Means that do not share a letter are significantly different.
```

Table A. 10 One-way ANOVA and Tukey's Comparison Test for swelling index of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                     DF       SS       MS      F      P
Extrusion temperature       1  0,38470  0,38470  49,26  0,002
Error                       4  0,03124  0,00781
Total                       5  0,41594
S = 0,08837   R-Sq = 92,49%   R-Sq(adj) = 90,61%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   --------+---------+---------+---------+-
HT     3  2,0792  0,1199                            (------*------)
LT     3  1,5728  0,0353   (------*------)
                           --------+---------+---------+---------+-
                                 1,60      1,80      2,00      2,20

Pooled StDev = 0,0884

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  2,07919  A
LT                     3  1,57276    B

Means that do not share a letter are significantly different.
```

Table A. 11 One-way ANOVA and Tukey's Comparison Test for swelling index of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF       SS       MS     F      P
Raw material   1  0,00666  0,00666  2,08  0,223
Error          4  0,01281  0,00320
Total          5  0,01947
S = 0,05658   R-Sq = 34,22%   R-Sq(adj) = 17,78%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   --------+---------+---------+---------+-
Fiber  3  1,5728  0,0353             (------------*------------)
Sem    3  1,5061  0,0718   (------------*------------)
                           --------+---------+---------+---------+-
                                 1,470     1,540     1,610     1,680

Pooled StDev = 0,0566

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Fiber           3  1,57276  A
Sem             3  1,50611  A

Means that do not share a letter are significantly different.
```

Table A. 12 One-way ANOVA and Tukey's Comparison Test for swelling index of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF       SS       MS      F      P
Raw material   1  0,16137  0,16137  17,32  0,014
Error          4  0,03726  0,00931
Total          5  0,19863
S = 0,09651   R-Sq = 81,24%   R-Sq(adj) = 76,55%

                          Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean   StDev    +---------+---------+---------+---------
Fiber  3  2,0792  0,1199                        (---------*---------)
Sem    3  1,7512  0,0652    (--------*---------)
                            +---------+---------+---------+---------
                          1,60      1,76      1,92      2,08

Pooled StDev = 0,0965

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Fiber           3  2,07919  A
Sem             3  1,75119    B

Means that do not share a letter are significantly different.
```

Table A. 13 One-way ANOVA and Tukey's Comparison Test for water absorption index of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                     DF      SS      MS       F      P
Extrusion temperature       1  333,73  333,73  301,52  0,000
Error                       4    4,43    1,11
Total                       5  338,16

S = 1,052   R-Sq = 98,69%   R-Sq(adj) = 98,36%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  ---------+---------+---------+---------+
HT     3  127,24   0,92                               (--*---)
LT     3  112,32   1,17  (---*--)
                         ---------+---------+---------+---------+
                              115,0     120,0     125,0     130,0

Pooled StDev = 1,05

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  127,239  A
LT                     3  112,323    B

Means that do not share a letter are significantly different.
```

Table A. 14 One-way ANOVA and Tukey's Comparison Test for water absorption index of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                    DF     SS     MS      F      P
Extrusion temperature      1  567,9  567,9  14,48  0,019
Error                      4  156,9   39,2
Total                      5  724,8

S = 6,263   R-Sq = 78,35%   R-Sq(adj) = 72,94%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  --+---------+---------+---------+-------
HT     3  147,94   4,29                      (---------*---------)
LT     3  128,48   7,75  (---------*----------)
                         --+---------+---------+---------+-------
                         120       130       140       150

Pooled StDev = 6,26

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  147,936  A
LT                     3  128,477    B

Means that do not share a letter are significantly different.
```

Table A. 15 One-way ANOVA and Tukey's Comparison Test for water absorption index of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source           DF     SS     MS      F      P
Raw material      1  391,4  391,4  12,75  0,023
Error             4  122,8   30,7
Total             5  514,3

S = 5,541   R-Sq = 76,12%   R-Sq(adj) = 70,15%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  -------+---------+---------+---------+--
Fiber  3  128,48   7,75                   (--------*--------)
Sem    3  112,32   1,17  (--------*--------)
                         -------+---------+---------+---------+--
                              110       120       130       140
Pooled StDev = 5,54

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Fiber           3  128,477  A
Sem             3  112,323    B
Means that do not share a letter are significantly different.
```

Table A. 16 One-way ANOVA and Tukey's Comparison Test for water absorption index of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source           DF      SS      MS      F      P
Raw material      1  642,50  642,50  66,76  0,001
Error             4   38,50    9,62
Total             5  681,00

S = 3,102   R-Sq = 94,35%   R-Sq(adj) = 92,93%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  -------+---------+---------+---------+--
Fiber  3  147,94   4,29                           (-----*-----)
Sem    3  127,24   0,92  (-----*-----)
                         -------+---------+---------+---------+--
                            128,0     136,0     144,0     152,0

Pooled StDev = 3,10

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Fiber           3  147,936  A
Sem             3  127,239    B

Means that do not share a letter are significantly different.
```

Table A. 17 One-way ANOVA and Tukey's Comparison Test for rehydration rate of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                 DF         SS         MS      F      P
Extrusion temperature   1  0,0000828  0,0000828  17,38  0,053
Error                   2  0,0000095  0,0000048
Total                   3  0,0000923
S = 0,002183   R-Sq = 89,68%   R-Sq(adj) = 84,52%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N      Mean     StDev   -+---------+---------+---------+--------
HT     2  0,057150  0,002899               (----------*----------)
LT     2  0,048050  0,001061   (----------*----------)
                               -+---------+---------+---------+--------
                              0,0420    0,0480    0,0540    0,0600

Pooled StDev = 0,002183

Grouping Information Using Tukey Method

Extrusion temperature  N      Mean  Grouping
HT                     2  0,057150  A
LT                     2  0,048050  A
Means that do not share a letter are significantly different.
```

Table A. 18 One-way ANOVA and Tukey's Comparison Test for rehydration rate of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                 DF         SS         MS       F      P
Extrusion temperature   1  0,0002002  0,0002002  297,73  0,003
Error                   2  0,0000013  0,0000007
Total                   3  0,0002016
S = 0,0008201   R-Sq = 99,33%   R-Sq(adj) = 99,00%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N      Mean     StDev  --+---------+---------+---------+-------
HT     2  0,070500  0,000707                            (----*----)
LT     2  0,056350  0,000919  (----*----)
                              --+---------+---------+---------+-------
                              0,0550    0,0600    0,0650    0,0700

Pooled StDev = 0,000820

Grouping Information Using Tukey Method

Extrusion temperature  N      Mean  Grouping
HT                     2  0,070500  A
LT                     2  0,056350    B

Means that do not share a letter are significantly different.
```

Table A. 19 One-way ANOVA and Tukey's Comparison Test for rehydration rate of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF         SS         MS      F      P
Raw material   1  0,0000689  0,0000689  69,94  0,014
Error          2  0,0000020  0,0000010
Total          3  0,0000709
S = 0,0009925   R-Sq = 97,22%   R-Sq(adj) = 95,83%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N      Mean     StDev  -------+---------+---------+---------+--
Fiber  2  0,056350  0,000919                    (-------*------)
Sem    2  0,048050  0,001061  (------*-------)
                              -------+---------+---------+---------+--
                                   0,0480    0,0520    0,0560    0,0600

Pooled StDev = 0,000992

Grouping Information Using Tukey Method

Raw marerial    N      Mean  Grouping
Fiber           2  0,056350  A
Sem             2  0,048050    B

Means that do not share a letter are significantly different.
```

Table A. 20 One-way ANOVA and Tukey's Comparison Test for rehydration rate of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF          SS          MS      F      P
Raw material   1  0,0001782  0,0001782  40,03  0,024
Error          2  0,0000089  0,0000045
Total          3  0,0001871
S = 0,002110   R-Sq = 95,24%   R-Sq(adj) = 92,86%

                              Individual 95% CIs For Mean Based on Pooled
StDev
Level  N      Mean     StDev  --------+---------+---------+---------+-
Fiber  2  0,070500  0,000707                    (--------*--------)
Sem    2  0,057150  0,002899  (---------*--------)
                              --------+---------+---------+---------+-
                                  0,0560    0,0630    0,0700    0,0770

Pooled StDev = 0,002110

Grouping Information Using Tukey Method

Raw material    N      Mean  Grouping
Fiber           2  0,070500  A
Sem             2  0,057150    B

Means that do not share a letter are significantly different.
```

Table A. 21 One-way ANOVA and Tukey's Comparison Test for L^* value of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                     DF      SS      MS     F      P
Extrusion temperature       1  0,4874  0,4874  5,42  0,080
Error                       4  0,3598  0,0899
Total                       5  0,8471
S = 0,2999   R-Sq = 57,53%   R-Sq(adj) = 46,91%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  --+---------+---------+---------+-------
HT     3  52,560  0,295                (-----------*-----------)
LT     3  51,990  0,305  (-----------*-----------)
                         --+---------+---------+---------+-------
                         51,60     52,00     52,40     52,80

Pooled StDev = 0,300

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  52,5600  A
LT                     3  51,9900  A
Means that do not share a letter are significantly different.
```

Table A. 22 One-way ANOVA and Tukey's Comparison Test for L^* value of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                    DF     SS     MS     F      P
Extrusion temperature      1  0,141  0,141  1,30  0,317
Error                      4  0,432  0,108
Total                      5  0,574
S = 0,3288   R-Sq = 24,60%   R-Sq(adj) = 5,75%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean  StDev    -+---------+---------+---------+--------
HT     3  48,760  0,282             (--------------*--------------)
LT     3  48,453  0,370    (--------------*--------------)
                           -+---------+---------+---------+--------
                         47,95     48,30     48,65     49,00

Pooled StDev = 0,329

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  48,7600  A
LT                     3  48,4533  A

Means that do not share a letter are significantly different.
```

Table A. 23 One-way ANOVA and Tukey's Comparison Test for L^* value of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF      SS      MS       F      P
Raw material   1  18,762  18,762  163,34  0,000
Error          4   0,459   0,115
Total          5  19,221
S = 0,3389   R-Sq = 97,61%   R-Sq(adj) = 97,01%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean  StDev    -+---------+---------+---------+--------
Fiber  3  48,453  0,370    (----*---)
Sem    3  51,990  0,305                                (---*----)
                           -+---------+---------+---------+--------
                         48,0      49,2      50,4      51,6

Pooled StDev = 0,339


Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Sem             3  51,9900  A
Fiber           3  48,4533    B

Means that do not share a letter are significantly different.
```

Table A. 24 One-way ANOVA and Tukey's Comparison Test for L^* value of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF       SS       MS       F      P
Raw material   1  21,6600  21,6600  260,34  0,000
Error          4   0,3328   0,0832
Total          5  21,9928
S = 0,2884   R-Sq = 98,49%   R-Sq(adj) = 98,11%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  --------+---------+---------+---------+-
Fiber  3  48,760  0,282  (---*---)
Sem    3  52,560  0,295                                 (---*---)
                         --------+---------+---------+---------+-
                              49,2      50,4      51,6      52,8

Pooled StDev = 0,288

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Sem             3  52,5600  A
Fiber           3  48,7600    B

Means that do not share a letter are significantly different.
```

Table A. 25 One-way ANOVA and Tukey's Comparison Test for a^* value of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                    DF      SS      MS     F      P
Extrusion temperature      1  0,2522  0,2522  3,73  0,126
Error                      4  0,2702  0,0675
Total                      5  0,5224
S = 0,2599   R-Sq = 48,27%   R-Sq(adj) = 35,34%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
HT     3  2,9600  0,2117  (-----------*----------)
LT     3  3,3700  0,3005             (-----------*-----------)
                          -------+---------+---------+---------+--
                              2,80      3,15      3,50      3,85

Pooled StDev = 0,2599

Grouping Information Using Tukey Method

Raw material  N    Mean  Grouping
LT            3  3,3700  A
HT            3  2,9600  A

Means that do not share a letter are significantly different.
```

Table A. 26 One-way ANOVA and Tukey's Comparison Test for a* value of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                     DF      SS      MS     F      P
Extrusion temperature       1  0,0417  0,0417  1,16  0,343
Error                       4  0,1443  0,0361
Total                       5  0,1859
S = 0,1899   R-Sq = 22,41%   R-Sq(adj) = 3,01%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   ---+---------+---------+---------+------
HT     3  2,8533  0,2570   (---------------*--------------)
LT     3  3,0200  0,0781            (--------------*--------------)
                           ---+---------+---------+---------+------
                            2,60      2,80      3,00      3,20

Pooled StDev = 0,1899

Grouping Information Using Tukey Method

Extrusion temperature  N    Mean  Grouping
LT                     3  3,0200  A
HT                     3  2,8533  A

Means that do not share a letter are significantly different.
```

Table A. 27 One-way ANOVA and Tukey's Comparison Test for a* value of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF      SS      MS     F      P
Raw material   1  0,1837  0,1837  3,81  0,123
Error          4  0,1928  0,0482
Total          5  0,3765
S = 0,2195   R-Sq = 48,80%   R-Sq(adj) = 36,00%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev    -+---------+---------+---------+--------
Fiber  3  3,0200  0,0781    (-----------*----------)
Sem    3  3,3700  0,3005                (----------*-----------)
                            -+---------+---------+---------+--------
                           2,70      3,00      3,30      3,60

Pooled StDev = 0,2195

Grouping Information Using Tukey Method

Raw material    N    Mean  Grouping
Sem             3  3,3700  A
Fiber           3  3,0200  A

Means that do not share a letter are significantly different.
```

Table A. 28 One-way ANOVA and Tukey's Comparison Test for a^* value of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF      SS      MS     F      P
Raw material   1  0,0171  0,0171  0,31  0,608
Error          4  0,2217  0,0554
Total          5  0,2387
S = 0,2354   R-Sq = 7,15%   R-Sq(adj) = 0,00%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev   -+---------+---------+---------+--------
Fiber  3  2,8533  0,2570   (--------------*--------------)
Sem    3  2,9600  0,2117       (--------------*--------------)
                           -+---------+---------+---------+--------
                          2,50      2,75      3,00      3,25

Pooled StDev = 0,2354

Grouping Information Using Tukey Method

Raw material    N    Mean  Grouping
Sem             3  2,9600  A
Fiber           3  2,8533  A

Means that do not share a letter are significantly different.
```

Table A. 29 One-way ANOVA and Tukey's Comparison Test for b^* value of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                    DF     SS     MS     F      P
Extrusion temperature      1  1,685  1,685  7,60  0,051
Error                      4  0,887  0,222
Total                      5  2,573
S = 0,4709   R-Sq = 65,52%   R-Sq(adj) = 56,89%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean  StDev     +---------+---------+---------+---------
HT     3  20,747  0,415                     (---------*----------)
LT     3  19,687  0,521     (----------*----------)
                            +---------+---------+---------+---------
                         18,90     19,60     20,30     21,00

Pooled StDev = 0,471

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
HT                     3  20,7467  A
LT                     3  19,6867  A

Means that do not share a letter are significantly different.
```

Table A. 30 One-way ANOVA and Tukey's Comparison Test for b^* value of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                    DF      SS      MS     F      P
Extrusion temperature      1  0,1873  0,1873  3,08  0,154
Error                      4  0,2431  0,0608
Total                      5  0,4303
S = 0,2465   R-Sq = 43,52%   R-Sq(adj) = 29,40%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  ------+---------+---------+---------+---
HT     3  14,917  0,244  (------------*------------)
LT     3  15,270  0,249              (------------*------------)
                         ------+---------+---------+---------+---
                            14,70     15,00     15,30     15,60

Pooled StDev = 0,247

Grouping Information Using Tukey Method

Extrusion temperature  N     Mean  Grouping
LT                     3  15,2700  A
HT                     3  14,9167  A

Means that do not share a letter are significantly different.
```

Table A. 31 One-way ANOVA and Tukey's Comparison Test for b^* value of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source        DF      SS      MS       F      P
Raw material   1  29,260  29,260  175,83  0,000
Error          4   0,666   0,166
Total          5  29,926
S = 0,4079   R-Sq = 97,78%   R-Sq(adj) = 97,22%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  ---+---------+---------+---------+------
Fiber  3  15,270  0,249  (----*---)
Sem    3  19,687  0,521                               (---*----)
                         ---+---------+---------+---------+------
                         15,0      16,5      18,0      19,5

Pooled StDev = 0,408

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Sem             3  19,6867  A
Fiber           3  15,2700    B

Means that do not share a letter are significantly different.
```

Table A. 32 One-way ANOVA and Tukey's Comparison Test for b* value of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source        DF      SS      MS       F      P
Raw material   1  50,983  50,983  439,01  0,000
Error          4   0,465   0,116
Total          5  51,448
S = 0,3408   R-Sq = 99,10%   R-Sq(adj) = 98,87%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  --------+---------+---------+---------+-
Fiber  3  14,917  0,244  (--*-)
Sem    3  20,747  0,415                               (--*-)
                         --------+---------+---------+---------+-
                              16,0      18,0      20,0      22,0

Pooled StDev = 0,341

Grouping Information Using Tukey Method

Raw material    N     Mean  Grouping
Sem             3  20,7467  A
Fiber           3  14,9167    B

Means that do not share a letter are significantly different.
```

Table A. 33 One-way ANOVA and Tukey's Comparison Test for firmness of pasta produced with only semolina at low temperature and high temperature

One-way ANOVA: Sem versus Extrusion temperature

```
Source                      DF     SS     MS     F      P
Extrusion temperature        1  1,356  1,356  4,59  0,099
Error                        4  1,180  0,295
Total                        5  2,536

S = 0,5432   R-Sq = 53,46%   R-Sq(adj) = 41,83%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
HT     3  5,6150  0,6146  (-----------*------------)
LT     3  6,5657  0,4607              (------------*-----------)
                          --+---------+---------+---------+-------
                          4,90      5,60      6,30      7,00

Pooled StDev = 0,5432

Grouping Information Using Tukey Method

Extrusion temperature  N    Mean  Grouping
LT                     3  6,5657  A
HT                     3  5,6150  A
Means that do not share a letter are significantly different.
```

Table A. 34 One-way ANOVA and Tukey's Comparison Test for firmness of pasta produced with lemon fiber at low temperature and high temperature

One-way ANOVA: Fiber versus Extrusion temperature

```
Source                     DF      SS      MS     F      P
Extrusion temperature       1  0,983  0,983  2,92  0,162
Error                       4  1,344  0,336
Total                       5  2,327

S = 0,5797   R-Sq = 42,23%   R-Sq(adj) = 27,79%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev  ------+---------+---------+---------+---
HT     3  4,7333  0,6414  (-------------*------------)
LT     3  5,5427  0,5105             (------------*------------)
                          ------+---------+---------+---------+---
                              4,20      4,90      5,60      6,30

Pooled StDev = 0,5797

Grouping Information Using Tukey Method

Extrusion temperature  N    Mean  Grouping
LT                     3  5,5427  A
HT                     3  4,7333  A

Means that do not share a letter are significantly different.
```

Table A. 35 One-way ANOVA and Tukey's Comparison Test for firmness of pasta produced at low temperature with only semolina and with lemon fiber

One-way ANOVA: LT versus Raw material

```
Source           DF     SS     MS     F      P
Raw material      1  1,570  1,570  6,64  0,062
Error             4  0,946  0,236
Total             5  2,515

S = 0,4862   R-Sq = 62,41%   R-Sq(adj) = 53,01%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
Fiber  3  5,5427  0,5105  (----------*----------)
Sem    3  6,5657  0,4607               (----------*----------)
                          --+---------+---------+---------+-------
                          4,90      5,60      6,30      7,00

Pooled StDev = 0,4862

Grouping Information Using Tukey Method

Raw material    N    Mean  Grouping
Sem             3  6,5657  A
Fiber           3  5,5427  A
Means that do not share a letter are significantly different.
```

Table A. 36 One-way ANOVA and Tukey's Comparison Test for firmness of pasta produced at high temperature with only semolina and with lemon fiber

One-way ANOVA: HT versus Raw material

```
Source          DF     SS     MS     F      P
Raw material     1  1,166  1,166  2,95  0,161
Error            4  1,578  0,395
Total            5  2,744

S = 0,6282   R-Sq = 42,49%   R-Sq(adj) = 28,11%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---+---------+---------+---------+------
Fiber  3  4,7333  0,6414  (-----------*------------)
Sem    3  5,6150  0,6146            (-----------*------------)
                          ---+---------+---------+---------+------
                           4,00      4,80      5,60      6,40

Pooled StDev = 0,6282

Grouping Information Using Tukey Method

Raw material    N    Mean  Grouping
Sem             3  5,6150  A
Fiber           3  4,7333  A

Means that do not share a letter are significantly different.
```

Table A. 37 One-way ANOVA and Tukey's Comparison Test for total dietary fiber content of raw material and pasta produced at both low and high temperature

One-way ANOVA: TDF versus Extrusion temperature

```
Source                     DF      SS      MS     F      P
Extrusion temperature       2  0,1369  0,0685  1,32  0,388
Error                       3  0,1557  0,0519
Total                       5  0,2927

S = 0,2278   R-Sq = 46,79%   R-Sq(adj) = 11,32%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level      N    Mean   StDev  ----+---------+---------+---------+-----
HT         2  9,4400  0,0594          (--------------*-------------)
LT         2  9,1100  0,3394  (-------------*--------------)
Sem+Fiber  2  9,1300  0,1923  (--------------*--------------)
                              ----+---------+---------+---------+-----
                                8,75      9,10      9,45      9,80
Pooled StDev = 0,2278

Grouping Information Using Tukey Method

Extrusion temperature         N    Mean  Grouping
HT                            2  9,4400  A
Sem+Fiber                     2  9,1300  A
LT                            2  9,1100  A
Means that do not share a letter are significantly different.
```

Table A. 38 One-way ANOVA and Tukey's Comparison Test for insoluble dietary fiber content of raw material and pasta produced at both low and high temperature

One-way ANOVA: IDF versus Extrusion temperature

Source	DF	SS	MS	F	P
Extrusioj temperature	2	0,0028	0,0014	0,05	0,950
Error	3	0,0811	0,0270		
Total	5	0,0839			

S = 0,1644   R-Sq = 3,34%   R-Sq(adj) = 0,00%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level      N    Mean   StDev  --+---------+---------+---------+-------
HT         2  6,1700  0,1994    (-----------------*------------------)
LT         2  6,1300  0,0396  (-----------------*------------------)
Sem+Fiber  2  6,1200  0,1994  (-----------------*-----------------)
                              --+---------+---------+---------+-------
                              5,80      6,00      6,20      6,40
```

Pooled StDev = 0,1644

Grouping Information Using Tukey Method

Extrusion temperature	N	Mean	Grouping
HT	2	6,1700	A
LT	2	6,1300	A
Sem+Fiber	2	6,1200	A

Means that do not share a letter are significantly different.

Table A. 39 One-way ANOVA and Tukey's Comparison Test for soluble dietary fiber content of raw material and pasta produced at both low and high temperature

One-way ANOVA: SDF versus Extrusion temperature

Source	DF	SS	MS	F	P
Extrusion temperature	2	0,1017	0,0509	0,64	0,586
Error	3	0,2376	0,0792		
Total	5	0,3393			

S = 0,2814   R-Sq = 29,98%   R-Sq(adj) = 0,00%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level      N    Mean   StDev   -+---------+---------+---------+--------
HT         2  3,2700  0,2602          (----------------*----------------)
LT         2  2,9800  0,3196   (----------------*---------------)
Sem+Fiber  2  3,0100  0,2602   (----------------*----------------)
                               -+---------+---------+---------+--------
                              2,40      2,80      3,20      3,60
```

Pooled StDev = 0,2814

Grouping Information Using Tukey Method

Extrusion temperature	N	Mean	Grouping
HT	2	3,2700	A
Sem+Fiber	2	3,0100	A
LT	2	2,9800	A

Means that do not share a letter are significantly different.

B. DSC THERMOGRAMS

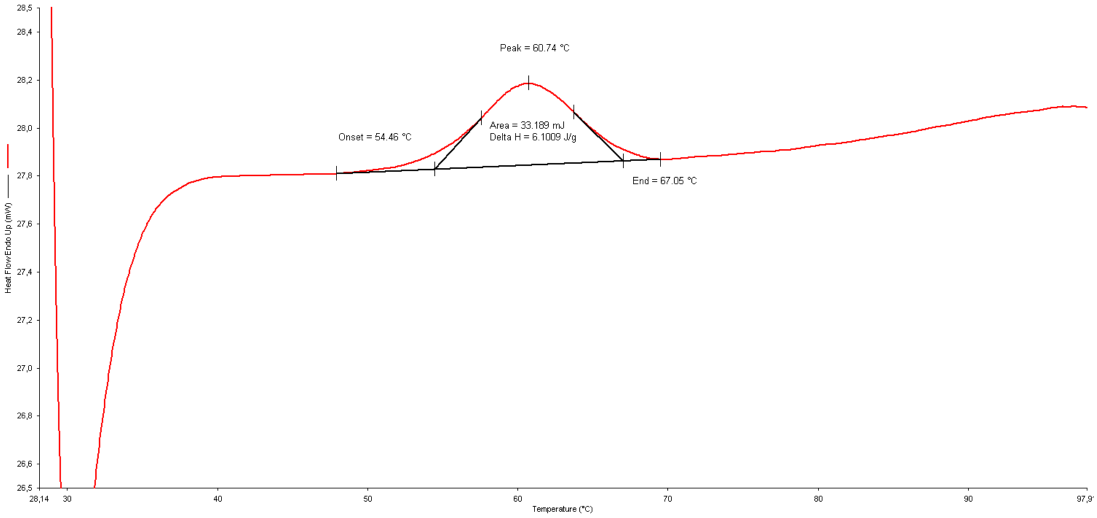

Figure B.1. DSC thermogram of semolina

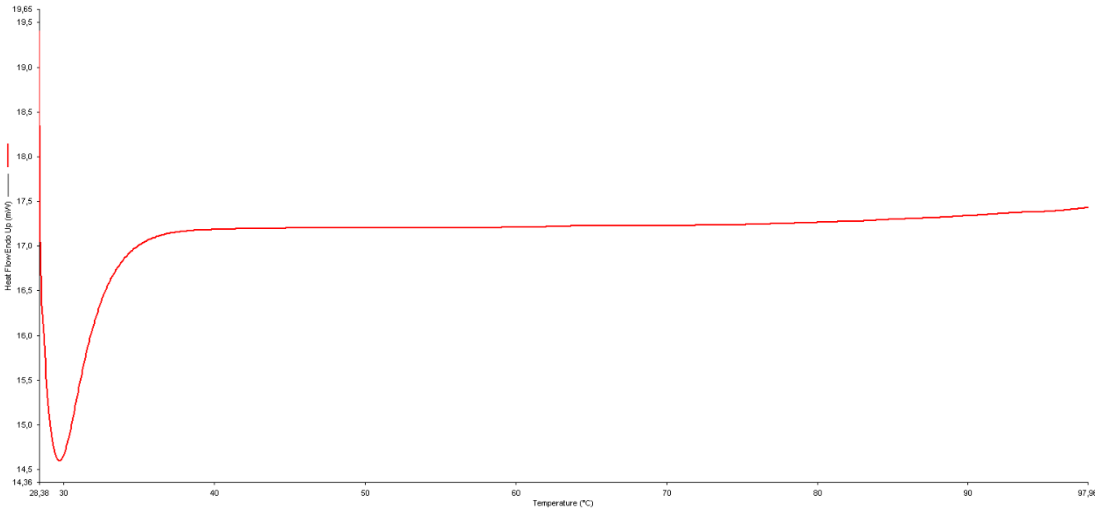

Figure B.2. DSC thermogram of pasta without fiber addition produced at low temperature (40ºC-40ºC-65ºC-45ºC)

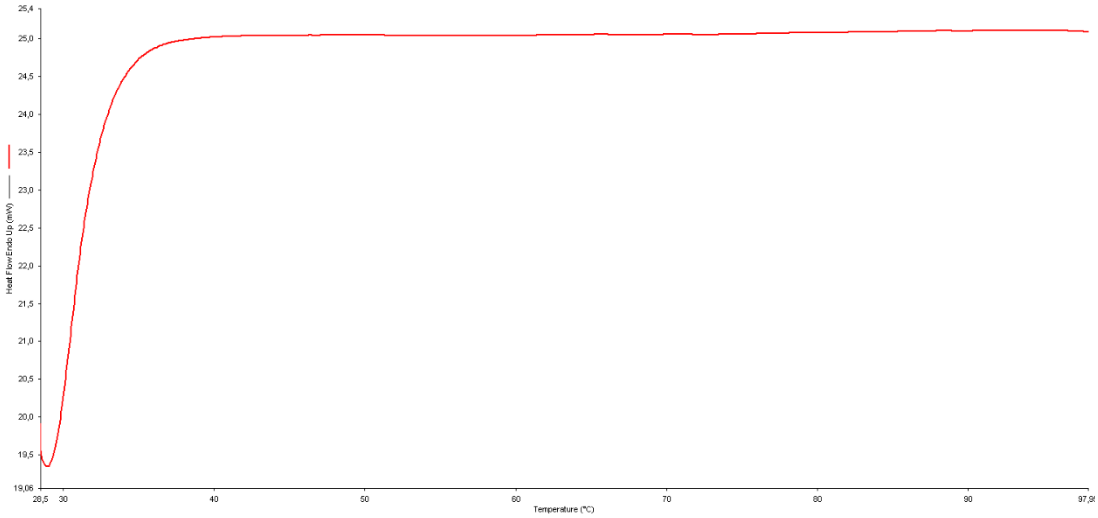

Figure B.3. DSC thermogram of pasta with fiber addition produced at low temperature (40ºC-40ºC-65ºC-45ºC)

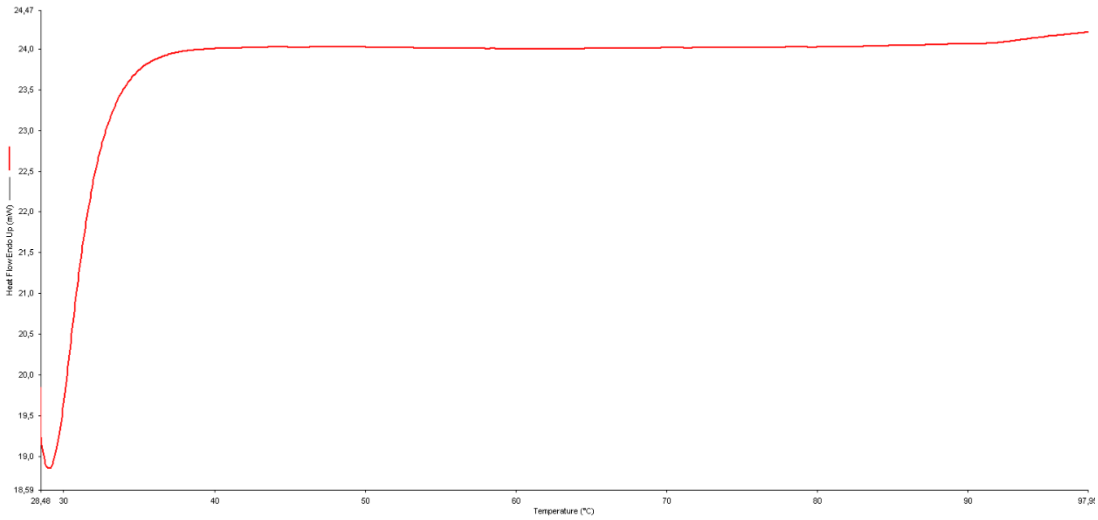

Figure B.4. DSC thermogram of pasta without fiber addition produced at high temperature (65ºC-65ºC-85ºC-70ºC)

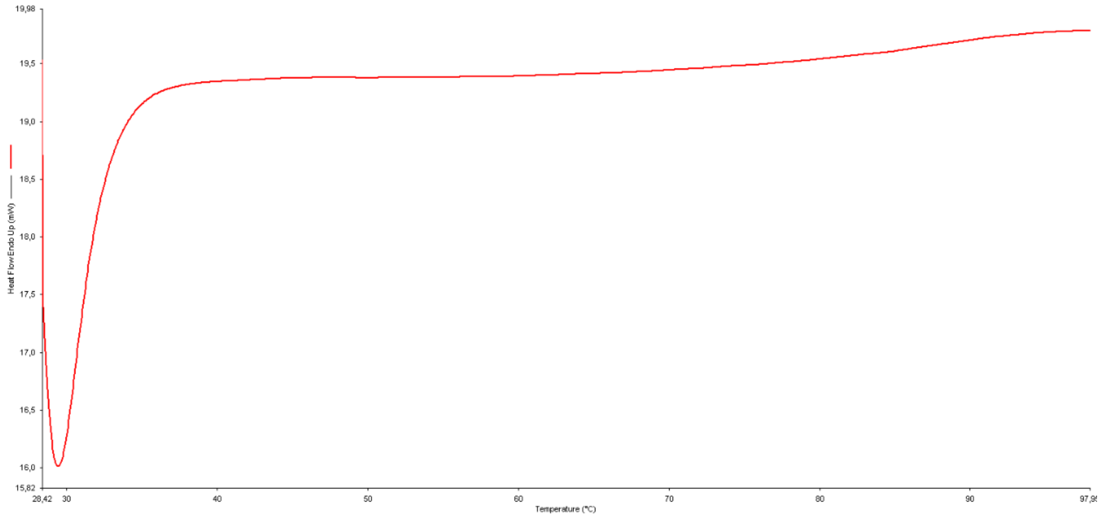

Figure B.5. DSC thermogram of pasta with fiber addition produced at high temperature (65ºC-65ºC-85ºC-70ºC)

C. SCHEMATIC DIAGRAM OF EXTRUDER

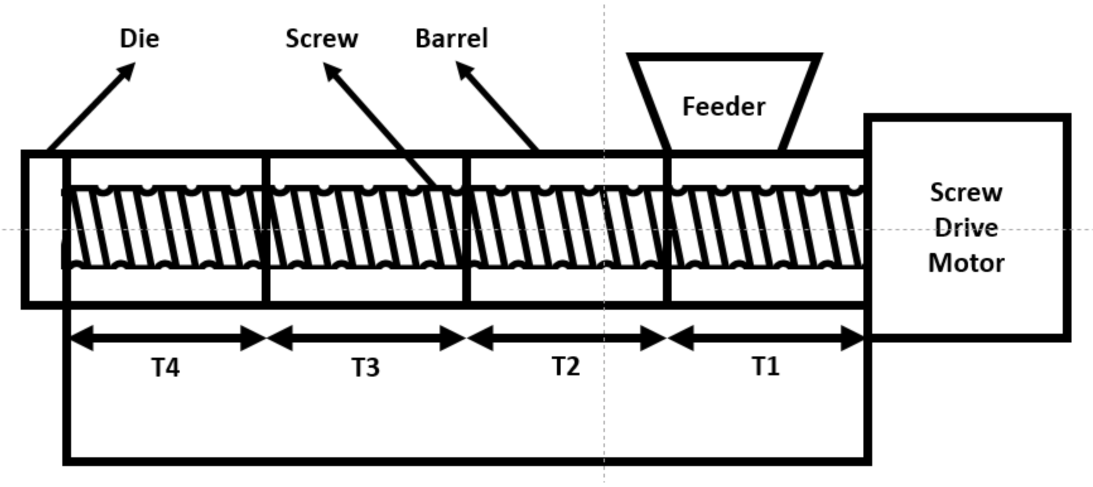

Figure C.1. Schematic diagram of extruder