EFFECT OF MICROFLUIDIZED ONION SKIN ADDITION ON THE QUALITY OF EXTRUDATES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ELÇİN BİLGİN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
FOOD ENGINEERING

FEBRUARY 2016

Approval of the thesis:

EFFECT OF MICROFLUIDIZED ONION SKIN ADDITION ON THE QUALITY OF EXTRUDATES

submitted by **ELÇİN BİLGİN** in partial fulfillment of the requirements for the degree of **Master of Science in Food Engineering Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver _____
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Alev Bayındırlı _____
Head of Department, **Food Engineering**

Assoc. Prof. Dr. İlkay Şensoy _____
Supervisor, **Food Engineering Dept., METU**

Prof. Dr. Behiç Mert _____
Co-supervisior, **Food Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Serpil Şahin _____
Food Engineering Dept., METU

Assoc. Prof. Dr. İlkay Şensoy _____
Food Engineering Dept., METU

Prof. Dr. Behiç Mert _____
Food Engineering Dept., METU

Prof. Dr. Servet Gülüm Şumnu _____
Food Engineering Dept., METU

Asst. Prof. Dr. Özge Şakıyan Demirkol _____
Food Engineering Dept., Ankara University

Date: 04.02.2016

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Elçin BİLGİN

Signature:

ABSTRACT

EFFECT OF MICROFLUIDIZED ONION SKIN ADDITION ON THE QUALITY OF EXTRUDATES

Bilgin, Elçin

M. S., Department of Food Engineering

Supervisor : Assoc. Prof. Dr. İlkay Şensoy

Co-supervisor : Prof. Dr. Behiç Mert

February 2016, 79 pages

The objective of the study was to investigate the effect of microfluidized onion skin addition on the features of expansion characteristics, water absorption index, water solubility index, color, texture and sensory of extruded products. In addition, addition of microfluidized and non – microfluidized onion skins to extruded products were compared.

Increasing microfluidized onion skin content in the samples caused a reduction in sectional expansion index (SEI), volumetric expansion index (VEI) and porosity of extruded samples while causing an increase in bulk density of extruded samples. Increasing microfluidized onion skin content in the extrudates did not cause any significant change in water absorption index (WAI) and water solubility index (WSI) values. Addition of microfluidized onion skin to feed decreased lightness while increased redness and yellowness of extrudates. Addition of microfludizied onion skin increased maximum stress, hardness, and brittleness. After 2% microfluidized onion skin addition, lower scores were observed in sensory data of extrudates.

SEI, VEI, porosity, bulk density, WAI, WSI, lightness values, maximum stress, hardness, fracturability and sensory data of extrudates with, microfluidized and non-microfluidized onion skin added samples at 6% indicated no significant difference. However, there was significant difference between microfluidized and non-microfluidized onion skins added samples in redness and yellowness values.

The results indicate that microfluidized onion skins at low concentration can be added to feed samples to increase the fiber content of the extrudates.

Keywords: Extrusion, microfluidization, onion skin

ÖZ

MİKRO AKIŞKANLAŞTIRILMIŞ SOĞAN KABUĞU EKLEMENİN EKSTRUDE ÜRÜNLERİN KALİTESİNE ETKİLERİ

Bilgin, Elçin
Yüksek Lisans, Gıda Mühendisliği Bölümü
Tez Yöneticisi : Doç. Dr. İlkay Şensoy
Ortak Tez Yöneticisi : Prof. Dr. Behiç Mert

Şubat 2016, 79 sayfa

Bu çalışmanın amacı mikro akışkanlaştırılmış soğan kabuğu eklemenin ekstrüde ürünlerin genleşme karakterleri, su emme indeksi, suda çözünülebilirlik indeksi, renk, tekstür ve duyusal özelliklerine etkisinin araştırılmasıydı. Buna ek olarak, mikro akışkanlaştırılmış ve mikro akışkanlaştırılmamış soğan kabuğunun ekstrüde ürünlere eklenmesi karşılaştırılmıştır.

Numunelerdeki mikro akışkanlaştırılmış soğan kabuğu içeriğinin artması ekstrüde ürünlerin enine genleşme indeksi, hacim genleşme indeksi, gözenekliliğinde azalma trendine sebep olmuştur oysaki bu durum ekstrüde ürünlerin yığın yoğunluğunda artmaya sebep olmuştur. Mikro akışkanlaştırılmış soğan kabuğu içeriğinin artması ekstrüdelerin su emme indeksi ve suda çözünebilirlik indeksi değişimlerinde anlamlandırılacak bir fark yaratmamıştır. Beslemeye mikro akışkanlaştırılmış soğan kabuğu eklemek ürün renginde parlaklık değerini azaltmış, kırmızılık ve sarılık değerini artırmıştır. Mikro akışkanlaştırılmış soğan kabuğunun ekstrüdeye eklenmesi maksimum gerilim, sertlik ve kırılganlık değerlerini artırmıştır. %2 oranından fazla eklenen mikro akışkanlaştırılmış soğan kabuğunun, ekstrüdelerin tadım değerlerinde bir düşme trendi yaptığı gözlemlenmiştir.

6% oranında mikro akışkanlaştırılmış ve mikro akışkanlaştırılmamış soğan kabuğu eklenen numunelerde, enine genleşme indeksi, hacim genleşme indeksi, gözeneklilik, yığın yoğunluğu, su emme indeksi, suda çözünebilirlik indeksi, parlaklık değerleri, en yüksek gerilme, sertlik, kırılganlık ve duyusal değerlerinde anlamlı bir fark olmadığı belirtilmiştir. Fakat mikro akışkanlaştırılmış ve mikro akışkanlaştırılmamış soğan

kabuğu eklenen numunelerin kırmızılık ve sarılık renk değerleri arasında anlamlı bir fark vardır.

Sonuçlar, ekstrüde ürünün lif oranını arttırmak için düşük konsantrasyonda mikro akışkanlaştırılmış soğan kabuğunun ürüne eklenebileceğini göstermektedir.

Anahtar kelimeler: Ekstrüzyon, mikro akışkandırıcı, soğan kabuğu

To my beloved family

ACKNOWLEDGEMENT

I would like to thank my advisor Assoc. Prof. Dr. İlkay Şensoy for her endless support, knowledge and encouragement throughout this study. She always tried to help me and it would be impossible to complete my study without her valuable suggestions. I am also grateful to my co-advisor Prof. Dr. Behiç Mert for his valuable advices and laboratory support throughout this study especially in the microfluidization process and texture parts of thesis.

I would like to thank members of my thesis committee, Prof. Dr. Servet Gülüm Şumnu, Prof. Dr. Serpil Şahin and Assist. Prof. Özge Şakıyan Demirkol for valuable comments. Also, I would like to thank Assist. Prof. Dr. Mecit Öztop for his laboratory support. I also want to thank Özge Güven, Bade Tonyalı, Çağla Çaltinoğu for their cooperative study in our researches, for supportive attidues to me, for all advices and for good times.

I would like to thank my sincerest to Sinem Şenol, Cansu Pıtır, Meltem Yamakoğlu Ülker, Ayça Sofu and Sevil Çıkrıkcı. They become members of my family, not only friends in my life. It would be difficult to complete this study without their endless support, love and motivation in my stressful days. I cannot thank them enough for everything in good and bad days of my life. Orçin Akgönül and Bora Durul deserve a special thanks to their supports in my life and they also can entertain all this time. Without them, it would be hard to achieve this study.

I would like to express my special thanks to Sevil Çıkrıkcı, Meltem Karadeniz, Özge Güven, Çağla Çaltinoğlu, Bade Tonyalı, Selen Güner, Ayça Aydoğdu, Emrah Kırtıl, Önay Burak Doğan, Sertan Cengiz, Ahmet Yıldız, Sezil Solta, Oğuz Kaan Öztürk, Hazal Turasan, Mert Cem Didiş, Başak Övet, Ece Bulut, Ali Übeyitoğulları, Armağan

Cabadağ, Elif Yıldız Bulut for their support and friendships during the time I spent at the department.

Finally, I would like to express my deepest appreciation to my family; my parents, Elif- Ertuğrul Bilgin, my brother, his wife, Ezel-Erkan Bilgin, and my niece Beliz Ada Bilgin for their endless support, unconditional love, encouragement and patience. Any word can express my gratitude and love to them. I dedicate this work to them.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

NOMENCLATURE

$\Delta V_{(glass\ cylinder)}$: Difference of volume of after and before addition of extruded sample (cm^3)

σ : Maximum stress (Mpa)

$\rho_{(bulk)}$: Bulk density of extruded sample (g /cm^3)

$\rho_{(paraffin)}$: Density of paraffin (0.9 g /cm^3)

$\rho_{(true)}$: True density of extruded sample (g/cm^3)

a* : Redness- greenness value

b* : Yellowness- blueness values

D_e : Diameter of the extrudates (mm)

D_d : Diameter of the die insert (mm)

F : Force (N)

IDF : Insoluble dietary fiber

L : Distance of two adjustable supports (m)

L* : Lightness values

L:D : The barrel length to diameter ratio

$m_{(dissolved)}$: Weight of supernatant in the petri dishes after drying process (g)

$m_{(dry)}$: Dry weight of extruded samples (g)

$m_{(paraffin)}$: Weight of paraffin (g)

$m_{(paraffin + sample)}$: Weight of paraffin covered extruded sample (g)

$m_{(sample)}$: Weight of extrudates without paraffin sample (g)

$m_{(sediment)}$: Weight of residue after pouring supernatant in the centrifuge tubes (g)

P_1 : Pressure of chamber 1 before opening valve between chamber 1 and 2

P_2 : Pressure of chamber 2 after opening valve and reaching equilibrium pressure

r : Radius of extruded samples (m)

SEI : Sectional expansion Index

SEM : Scanning electron microscope

SME : Specific mechanical energy

VEI : Volumetric expansion index

$V_{(marble)}$:Volume of marble (cm^3)

$V_{(paraffin)}$: Volume of paraffin (cm^3)

$V_{(sample)}$: Volume of extruded sample (cm^3)

$V_{(true)}$: True volume of extruded sample (cm^3)

$V_{(chamber\ 1)}$: Volume of chamber 1 (cm^3)

$V_{(chamber\ 2)}$: Volume of chamber 2 (cm^3)

VEI : Volume expansion index

WAI : Water absorption index

WSI : Water solubility index

WHC : Water holding capacity

CHAPTER 1

INTRODUCTION

During production, preparation and consumption of foods, the food industry creates huge volume of solid and liquid wastes. In today's world, recovery, recycling, upgrading of wastes are important issues due to environmental problems, decreasing availability of raw materials, and rising costs. For food industry, wastes, effluents, residues and by products can be recovered and upgraded to higher value. In the past, wastes were thought as garbage, fertilizers, and animal feed which were used without treatment. Over time, awareness has increased to prevent environment pollution, to increase conservation of energy and to provide better economic situations. Thus, policies for waste management and also treatments to recovery, bio conservation and usage of valuable parts of food processing wastes have arisen. Food processing wastes might be used as raw materials by recycling or additional ingredients as higher value by-product by conversion. Additionally, they can be used as raw materials for different industries and also as food or feed after biological improvements (Laufenberg et al., 2003).

By upgrading vegetable wastes and beverage wastes, by-products and residues become more valuable products. Several innovative products could be determined. For instance, crude fibre of vegetable pomace is used as bread improver due to high fibre content. The main part of residual materials is insoluble fiber. Functionality of insoluble fiber could be improved by several methods like alkaline H_2O_2 treatment, extrusion, encapsulation with soluble fibre or modified to enhance sensory features (Laufenberg et al., 2003).

1.1 Onion Waste

In European Union, amount of onion waste are yearly of above 500,000 tons (Waldron, 2001). One of the usage of onion waste is organic fertilizers but onion wastes could have phytopathogens (Schieber et al., 2001).

Benitez et al. (2011) studied effect of thermal sterilization on onion by-products as stabilization treatment. Fibre fractions and composition, physicochemical properties of onions were investigated after sterilization which was done at 115^{o}C for 17- 31 minute. Because of the ratio of soluble dietary fiber to insoluble dietary fiber as 1:3, one of the usages of onion by-products might be as a source of soluble dietary fiber in foods due to decrease the feeling of hunger, reduction the time of absorption of foods. After sterilization process, reduction of insoluble dietary fiber (IDF) content in paste and bagasse parts of onions was observed at 13- 31 %. Decreasing the ratio of IDF might be attributed to effect of heat treatment on cellulose and hemicelluloses due partial degradation (Rehman et al., 2003).

In the study of Jaime et al. (2002), onion tissues were investigated for their fiber contents. This study showed that ratio of soluble dietary fiber to insoluble dietary fiber was decreasing going from inner to outer part of the onion tissue. Moreover, brown skin of onion tissues had the highest dietary fiber content as 65.8% on dry matter basis. Furthermore, main insoluble dietary fiber (IDF) content from outer two leaves and inner part were different.

According to Choi et al. (2015) glucose and uronic acid were main carbohydrates of onion skin waste. Moreover, klason lignin, ash, xylose, mannose, rhamnose, arabinose, galactose existed in these onion skin waste samples. However, chemical composition ratio of onion tissue could be changed due to type of cultivar, stage of maturation, environmental conditions, storage time, bulb section and agronomic conditions (Ng et al., 2000).

1.2 Microfluidization Process

One of the enhancement methods of texture, stability, color and taste of foods is microfluidization method. Microfluidization process relies on performing high pressure homogenization technique to the samples (Lagoueyte & Paquin, 1998). Reduction of particle size causes changes on rheological and sensory features of the samples (Ciron et al., 2011).

In Figure 1, the fluid passes through two micro channels in microfluidization process. Then, the fluid comes into collision in the reaction chamber at very high speeds (Cook et al., 1987; Lagoueyte & Paquin, 1998). Fine particles are formed by applying high shear rate and extreme impact forces to micro channel (McCrae, 1994; Mert, 2012). Due to high shear rate, macro particles are transformed to nano and micro particles. As a result of microfluidization process, microfluidized samples produce smaller particles than samples which pass through conventional valve homogenizer (Tunick et al., 2011).

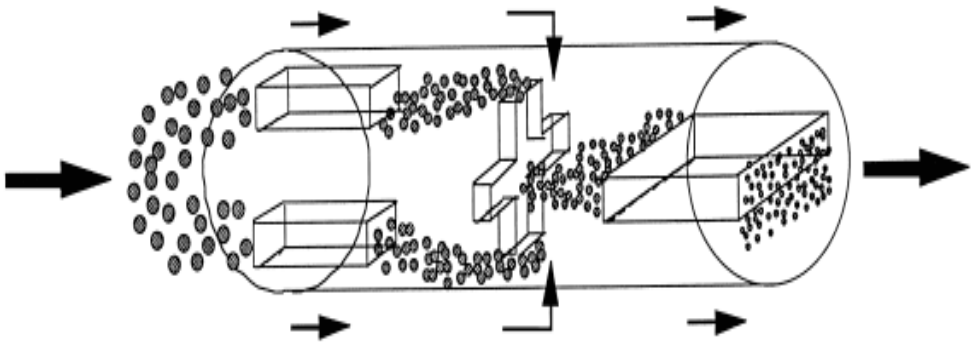

Figure 1. Symbolic configuration of the microfluidization process (Lagoueyte & Paquin, 1998).

There have been numerous studies about the effect of microfluidization process on the food samples such as milk (Dalgleish et al., 1996; Hardham et al., 2000), cream liqueurs (Paquin & Giasson, 1989), ice cream (Olson et al., 2003), mozzerella cheese (Tunick et al., 2000), yoghurt (Ciron et al., 2010), wheat bran (Wang et al., 2012), high methoxyl pectin (Chen et al., 2012), lentinan (Huang et al., 2012), ketchup (Mert, 2012), hazelnut skin addition (Çıkrıkcı, 2013; Yıldız, 2014) and zein (Öztürk, 2014). Microfluidization process affects enzymes (Liu et al., 2009), proteins (Zhang et al., 2009) and dietary fibers (Wan et al, 2009).

When compared with other homogenization techniques, microfluidization process is faster. Moreover, microfluidization process provides more uniform structure and provides smaller particle size. In addition, for small batch processes, achievement of continuous production occurs in the microfluidization process (Garad et al., 2010). Even though the advantages stated above, microfluidization process is not considered as a practical application due to high equipment cost (Tadros et al., 2004).

According to Wang et al. (2012), microfluidization process caused reduction of particle size and increased surface area in wheat bran samples. Wang et al. (2013) found similar results for reduction of particle size and increasing gradually specific surface area for corn bran after passing through microfluidization process.

Water holding capacity (WHC), swelling capacity (SC), and bulk density of samples may be altered after microfluidization process. According to Wang et al. (2012), particle size distribution might affect the hydration features of samples. Increasing water holding capacity of wheat bran was occurred by reduction of particle size and increasing particle size after passing through microfluidization process. Thus, microfluidized wheat bran had higher water holding capacity than raw wheat bran. However some incoherence results were showed that particle size distribution was not the only reason to change of water holding capacity. In the study of Zhang & Moore (1997), there was a reverse relation for wheat bran. Effect

of methods to samples on water holding capacity, porosity and bulk density is not the same for all methods. In the study of Huang et al. (2010), ball milled fibers showed increased porosity and lower bulk density.

In the study of Wang et al. (2012), swelling capacity of wheat bran was affected microfluidization process. The biggest increase of swelling capacity of wheat bran was occurred at the first microfluidization pass which was done by passing through at interaction chambers with a diameter of 200 μm. As particle size decreased, increasing trend of swelling capacity continued in the increasing passing number of microfluidization.

According to Wang et al. (2012), after microfluidization process, reduction particle size of samples can occur. On the other hand, expansion of samples in the liquid solution can occur too. The reason of this expansion of samples could be explained by rapid release of pressure. Pore formation, cavities and loosed microstructure of particles occurred after microfluidization (Chau et al., 2006). Due to modified microstructure and reduced particle size of samples, bigger surface area and increasing water binding (such as polar or uronic acid groups capacity) to surrounding water (Chau et al., 2006) could been.

1.3. Extrusion

1.3.1 Extrusion Technology

Extrusion process has some features which are mixing, kneading, shaping in a barrel, and samples are passed through a die to produce wide variety products (Akdogan, 1999). Extrusion technology is a low cost process compared to other types of cooking and shaping processes. Moreover, extended range of products such as food and pet foods exist. Extrusion process is a short time and high temperatures process (Guy, 2001; Riaz, 2001).

Extrusion means that liquid to semi liquid mixture passes through until the die part of the equipment to exit in the desired form. Temperature of barrels in the extrusion process can reach to 180 – 190^{o}C. However, residence time is short and could be about 20- 40 seconds (Riaz, 2001).

1.3.2 Extruder Types

1.3.2.1 Single – Screw Extruders

The aim of the screw part of extrusion is to convey, compress, melt and plasticize the samples and also pass samples through to die holes under certain pressure conditions. Materials which has high friction coefficient are proper to be used in the single–screw extruder process. Poor mixing of the samples is the basic disadvantage of single- screw extruders. Mixing should be done properly before feeding in multi-component mixtures. Efficiency of single screw extrusion cooking is limited when different ingredients were added to samples (Moscicki & Zuilichem, 2011).

Figure 2 shows a monoblock screw- barrel assembly of the single screw extruder. In compressing section, compressive effect of screw to samples occurs. Moreover, melting occurs in this section due to heating energy of interparticular friction and conductive heat transfer (Bouvier & Campanella, 2014).

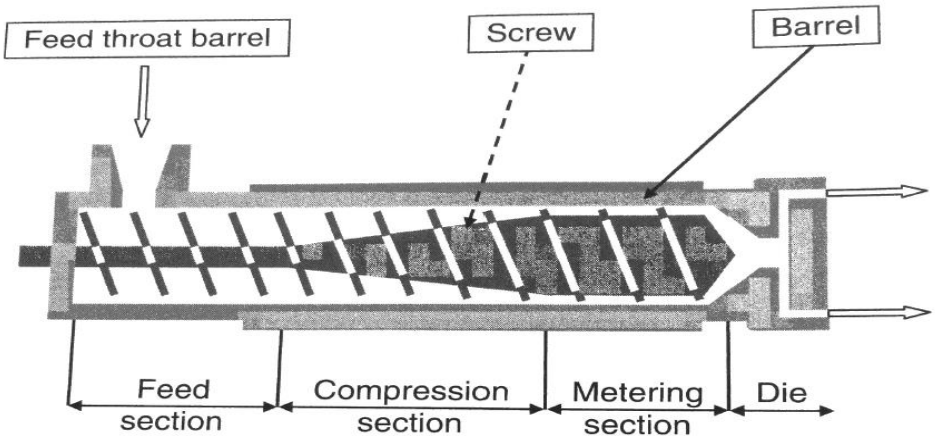

Figure 2 Monobloc Screw- barrel assembly of the single screw extruder (Bouvier & Campanella, 2014).

1.3.2.2 Twin – Screw Extruders

Twin- screw extruders are extruders which have two screws of equal length placed inside the same barrel (Guy, 2001). Figure 3 shows a screw- barrel assembly of the twin- screw extruder. There are only two disadvantages of this process which are being more complicated and cost of acquisition (Moscicki & Zuilichem, 2011).

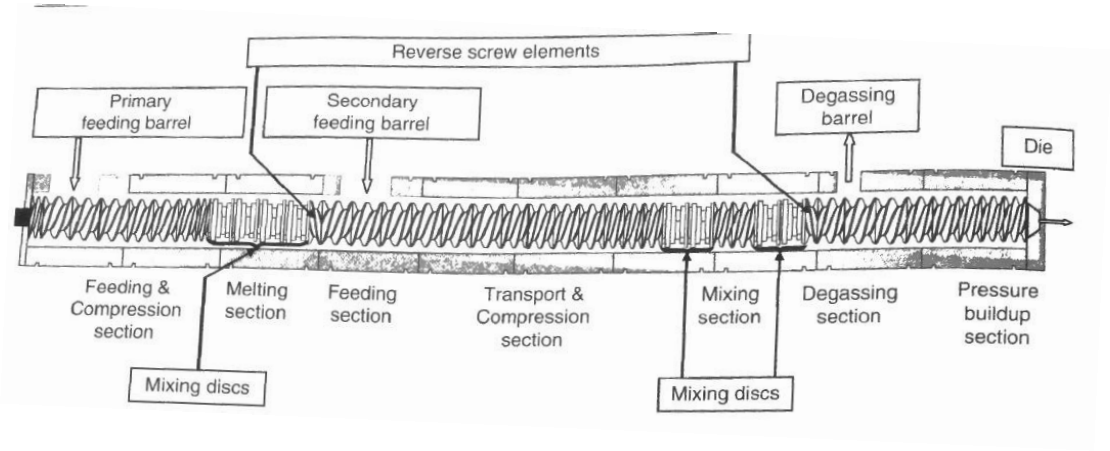

Figure 3 Screw- barrel assembly of the twin- screw extruder (Bouvier & Campanella, 2014).

Usage areas of twin screw extruders are wide and includes breakfast cereals, pet foods and dutched (alkali) cocoa (Kazemzadeh, 2012). Twin screw extruders have some important features such as high versatility (could also be used for viscous and not easy to break samples), lower energy consumption (Moscicki & Zuilichem, 2011), less residence time than single screw type extruders (Kazemzadeh, 2012), need short time to clean process, ability to manipulate outlet and operation conditions easily (Riaz, 2001). In Table 1, differences of process parameters for single screw extruders and twin screw extruders in the wet extrusion are shown. Twin screw extruders are designed as counter or co rotating types.

Table 1 Typical process parameters for single screw extruders and twin screw extruders in the wet extrusion (Riaz, 2001)

	Single-screw extruder	**Twin-screw extruder**
Range of Temperature (ºC)	80- 140	60-160
Maximum pressure (bar)	15- 30	15- 40
Moisture content (%)	15- 35	10 – 45
Starch Gelatinization (%)	80 – 100	80 -100

1.3.2.2.1 Counter–Rotating Twin-Screw Extruders

Counter- rotating types of twin extruders are suitable for high viscous samples (Moscicki & Zuilichem, 2011). Usage areas of counter- rotating types of twin

extruders are generally confectionery, chewing- gum and samples which have fiber and high concentration of cellulose ingredients (Moscicki & Zuilichem, 2011).

Due to specific working conditions, counter- rotating types of twin extruders are special-purpose machinery. Rotation speed of counter - rotating types of twin extruders are low however the samples can be mixed efficiently in the extruders (Moscicki & Zuilichem, 2011). By positive displacement, the samples in the extruders can move forward and also developing back flow of the samples are very rare due to too small gaps between the screws and the barrels (Moscicki & Zuilichem, 2011).

1.3.2.2.2 Co- Rotating Twin -Screw Extruders

Usage areas of co-rotation twin screw are too wide due to some properties of these extruder types such as high yield ratio, fine mixing and high screw speed (Moscicki & Zuilichem, 2011). Due to features of flights of the screws as being self-wiping and intermeshing, melt is not stucked into the barrel and screws. As a result of this situation, co rotating twin screw extruders can be thought as a self-cleaning equipments (Moscicki & Zuilichem, 2011).

1.3.3 Screw Elements and Kneading Disks

Changing screw elements and kneading disks on the screw shaft in the twin- screw food extruders could be done (Moscicki & Zuilichem; Bouvier & Campanella, 2014). Alterations of these elements and disks could provide to better mixing, compressing and melting in the extruders (Moscicki & Zuilichem, 2011).

1.3.4 Extrusion Processes

1.3.4.1 Parameters Affecting the Final Product

According to Riaz (2000), major and minor elements affect extruded products in terms of their chemical and physicochemical properties (Table 2). These parameters affect applied shear to the samples, residence time, and viscosity of the samples during passage through the barrel of the extruder (Riaz, 2000).

Table 2 Major and minor important elements for extruded samples (Riaz, 2000)

Major Elements	Minor Elements
Extruder model and temperature of barrels	Mass temperature
Configuration, speed of screw and die geometry	Pressure of the die
Features of feeds (structure, moisture content, particle size, rate of feed)	Specific Mechanical Energy (SME)

1.3.4.2 Extruded Products

Consumer and regulatory requirements are two fundamental requirements for food production. Consumer requirements depend on sensory features of products, bulk density and microbiological quality. The regulatory requirements relies on packaged products, composition and nutritional values of products (Chessari & Sellahewa, 2001).

Extrusion process can be accepted as high temperature short time process (Riaz, 2001) and residence time of this process is quitely smaller than residence time of other conventional thermal heating process. Formation of colors and flavours depend on maillard reaction during process (Chessari & Sellahewa, 2001). Due to vaporized water and volatile contents (Chessari & Sellahewa, 2001, Riaz, 2001) and short residence time (Guy, 2001), strong flavours of products cannot be produced (Chessari & Sellahewa, 2001). As a result of being less palatable products, most extruded products are dried and addition of flavours to products is done by oil emulsion spraying method (Chessari & Sellahewa, 2001).

Texture is one of the quality parameters of extruded products. In extrusion process, reduction of pressure occurs after passing through in the die to exit of the extruder. In that part, water content of materials turns into vapor from liquid. Stretching of products occurs by formation of bubbles due to water vapour and also matrix setting occurs as a result of evaporative cooling. Puffed structure of products is developed by air bubbles in the matrix (Chessari & Sellahewa, 2001).

Cell size distribution and cell wall thickness have effect on texture of extrudates (Chessari & Sellahewa, 2001). In the study of Barrett & Peleg (1992), results of increasing bulk density with constant cell size are due to formation of thicker cell walls in the extrudates. This indicates a requirement of bigger forces to compress the extrudates (Barrett & Peleg, 1992). Rheology features of melt influences expansion ratios of extruded products and texture (Chessari & Sellahewa, 2001; Riaz, 2000).

Bulk density is another important feature of extruded products for industry due to filling weight in the extrudates. As a result of this, in the industry, companies do regular analysis of bulk densities of extrudates to have proper product. It can be said that bulk density is an important quality assurance issue. Bulk density is affected by moisture content and the die design (Chessari & Sellahewa, 2001).

Shape and size of extrudates are the other important features of products for industry. The variations of shape and size of extrudates can be altered by changing the design of the die, rotating knife and rotation speed of the knife (Chessari & Sellahewa, 2001).

Microbiological aspect of extruded products is one of the most vital quality parameters for consumers. Generally, extruded products are considered as safe products due to exposed heat treatments and low water activity. In commercial extruded product, moisture content was reduced to less than 5% moisture content (Chessari & Sellahewa, 2001).

1.3.5 Effect of Dietary Fiber Addition on Extruded Products

According to The American Association of Cereal Chemist (1999), dietary fibers consist of polysaccharides, oligosaccharides, lignin and some plant matters. Definition of dietary fibers is edible carbohydrates with at least ten monomeric units and endogenous enzymes cannot hydrolyze them in the small intestine of human body (Codex, 2009). Recommended consumption ratios of dietary fibers correlate with age, gender and energy intake of people. Adequate intake of dietary fiber is 14 g/1000 kcal (USDA, 2005).

Dietary fibers can reduce risk of coronary heart disease, stroke, hypertension, diabetes, obesity and some gastrointestinal diseases. Moreover, high intakes of dietary fiber enhance the reduction of serum cholesterol levels and blood pressure and they also help to regulate glycemia and insulin sensitivity of human. Furthermore, higher intakes of dietary fiber increase weight loss (Anderson et al., 2009).

Classification of dietary fibers is soluble and insoluble dietary fibers. Soluble dietary fibers are viscous and have the ability to ferment in the colon (such as inulin). Insoluble ones have bulking action and also have limited ability to ferment in the colon (such as wheat bran) (Anderson et al., 2009).

Yanniotis et al. (2007), Chang et al. (1998) and Wang et al. (1993) observed a decrease in expansion with incorporation of wheat fiber as insoluble dietary fiber into corn starch. This result could be due to premature rupture of gas cells so overall expansion reduced and also porosity decreased. There was significant difference in radial expansion and porosity between extrudates with addition of 10% wheat fiber to corn meal and control samples (100% corn melt). Moreover, Brennan et al. (2008) studied that effect of inclusion of soluble and insoluble fibre to wheat flour melt to determine physical and nutritional properties of extrudates. For addition of fibre, wheat bran, fine guar gum, inulin, hi maize and swede fibre were used at 5%- 10%- 15% fibre ingredients to wheat flour. Increasing addition of bran and swede ingredients resulted in decreasing expansion ratio. In contrast, addition of inulin and hi maize caused significantly bigger expansion ratio of extrudates comparing to control samples. Guar gum ingredient had similar increasing effect except 15% ratio (Decreasing of expansion ratio occurred at 15% addition of guar gum). For bulk density, addition of bran and inulin content caused to have bigger bulk density than wheat flour melt (control sample) whereas addition of hi- maize caused to smaller bulk density then control sample. By contrast, gum and swede fiber had similar bulk density value comparing with bulk density of control sample.

1.4 Objectives of the Study

The aim of the study was to investigate the effect of microfluidized onion skin addition on the quality of extrudates. In addition, quality of extrudates with microfluidized and non- microfluidized onion skin were compared.

CHAPTER 2

MATERIAL AND METHOD

2.1 Material

The wheat flour was purchased from a producer (Söke Değirmencilik Sanayi ve Ticaret A.Ş., Aydın, Turkey). Onion skins were collected from local market (Ankara, Turkey). After collecting onion skins, they were washed with water. Drying processing of onion skins was done at room temperature for 3 days. Onion skins were grinded by a grinder (Pulverisette 16, Fritsch GmbH Milling and Sizing, Germany) which had a sieve 120 μm.

2.1.1 Production of Microfluidized Onion Skins

Grinded onion skins were microfluidized with a microfluidizer equipment (M-110Y, Microfluidics, USA). Hot water was added to onion skins at 1/10 ratio to soften the onion skins. Sodium hydroxide (Riedel–de Haen, Germany) was added to the slurry at the ratio of 5/1000. The slurry was kept at room temperature for a day. Excess water removed by using a strainer, remaining slurry was passed through colloid mill (IKA Magic Lab, IKA–Werke GmbH & Co. KG, Germany). Then, the mixture was passed through microfluidizer which had two chambers which were 200 μm and 100 μm size at 15000 Psi. Samples were put into zip lock bags and then frozen at –80°C (CL Hetofrig, Heto, Scandinavia). Microfluidized samples

were dried in a freeze dryer (Christ, Alpha 2-4 LD plus, Germany) for 48 hours at a pressure below 0.5mbar at- 70 -80ºC. Dried microfluidized onion skins were grinded by a grinder machine (Pulverisette 16, Fritsch GmbH Milling and Sizing, Germany) which had a sieve 120 μm.

2.2. Methods

2.2.1. Extrusion

Wheat flour was mixed with predetermined amount of grinded onion skins (6 % dry basis) or microfluidized onion skins (0%, 2%, 6%, 10% dry basis). Distilled water was added to have a final moisture content of 20% and mixed in a mixer (Kitchen Aid, Ariston, USA). Halogen moisture analyzer at 160ºC (MX-50, AND, Japan) was used to measure moisture content of the samples. Samples were put into plastic bags and stored at the cold room at 4ºC overnight. Prepared feed samples equilibrated at room temperature for 3 hours before the extrusion process.

Co-rotating twin screw extruder (Feza Gıda Müh. Makine Nakliyat ve Demir Tic. Ltd. Şti., İstanbul, Turkey) was used for experiments. The die diameter was 3mm and the barrel length to diameter ratio was (L:D) 25:1.The extruder had four heating zones controlled by electrical heating and water cooling. Computerized data acquisition system was used to control the barrel zone temperatures and screw speed. The feed was fed to the extruder with a twin screw volumetric feeder which was built into the extruder system.

Flow rate of all samples was 50 g/min and screw speed was 250 rpm. Barrel temperature zones were set at 70 ºC, 80 ºC, 130 ºC and 150 ºC for all samples and die temperature was kept at 130 ºC. Samples were taken only when temperature variations was ± 2.5ºC.

After the extrusion all samples were cut into 5 cm pieces and dried at 50 ºC for 15 hours in the oven (Binder, Germany) to reduce the moisture content below 4%. The dried samples were stored at room temperature until the analysis in the nylon bags.

2.2.2 Bulk Density

Bulk densities of samples were analyzed by using the liquid displacement method derived from Archimedes' principle. Extruded samples were weighted. Then, samples were sunk into melted paraffin (Merck KGaA, Germany) by tweezers, and left at room temperature to dry. After drying, extrudates covered with paraffin was weighted and submerged into graduated cylinder filled with distilled water. Bulk densities of the samples calculated with the following equations. Six measurements were taken and averaged.

$$m_{(paraffin)} = m_{(paraffin+sample)} - m_{(sample)} \quad (1)$$

$$V_{(paraffin)} = \frac{m_{(paraffin)}}{\rho_{(paraffin)}} \quad (2)$$

$$V_{(sample)} = \Delta V_{(glass\ cylinder)} - V_{(marble)} - V_{(paraffin)} \quad (3)$$

$$\rho_{(bulk)} = \frac{m_{(sample)}}{V_{(sample)}} \quad (4)$$

Where, $m_{(paraffin)}$: Weight of paraffin (g)

$m_{(paraffin + sample)}$: Weight of paraffin covered extruded sample (g)

$m_{(sample)}$: Weight of extrudates without paraffin (g)

$V_{(paraffin)}$: Volume of paraffin (cm^3)

$\rho_{(paraffin)}$: Density of paraffin (0.9 g /cm^3)

$V_{(sample)}$:Volume of extruded sample (cm^3)

$V_{(marble)}$:Volume of marble (cm^3)

$\Delta V_{(glass\ cylinder)}$: Difference of volume of after and before addition of the sample (cm^3)

$\rho_{(bulk)}$: Bulk density of extruded sample (g /cm^3).

2.2.3 True Density (Particle Density)

A helium pycnometer (Quantachrome Ultrapycnometer 1000, Florida, USA) was used at Middle East Technical University Central Laboratory for true density analysis. True density of the samples were calculated according to equation below. Three measurements of extruded samples were taken and averaged.

$$V_{(true)} = V_{(chamber\ 2)} - V_{(chamber\ 1)} \left(\frac{P_1 - P_2}{P_2}\right) \quad (5)$$

$$P_{(true)} = \frac{m_{(sample)}}{V_{(true)}} \quad (6)$$

Where, $V_{(true)}$: True volume of extruded sample (cm^3)

$V_{(chamber\ 1)}$: Volume of chamber 1 (cm^3)

$V_{(chamber\ 2)}$: Volume of chamber 2 (cm^3)

P_1 : Pressure of chamber 1 before opening valve between chamber 1 and 2

P_2 : Pressure of chamber 2 after opening valve and reaching equilibrium pressure

$\rho_{(true)}$: True density of extruded sample (g/cm^3)

$m_{(sample)}$: Weight of extruded sample (g).

2.2.4 Sectional Expansion Index (SEI)

Diameter of the extruded samples was measured with a digital caliper (SR- 44, Insize, Turkey). Sectional expansion index was calculated according to the equation below (Alvarez-Martinez et al., 1988).

$$SEI = \left(\frac{D_e}{D_d}\right)^2 \quad (7)$$

Where, D_e : Diameter of the extrudates (mm)

D_d : Diameter of the die insert (mm).

2.2.5 Volume Expansion Index (VEI)

Volumetric expansion index was calculated as in eqn. 8 (Pai et al., 2009).

$$VEI = \left(\frac{\rho_{true}}{\rho_{bulk}}\right) \quad (8)$$

Where VEI : Volume expansion index of extruded samples

$\rho_{(bulk)}$: Bulk density of the extruded sample (g/cm^3)

$\rho_{(true)}$: True density of the extruded sample (g/cm^3).

2.2.6 Porosity

Porosity was calculated by using bulk and true density of sample (Lin et al., 1967), as shown in eqn 9.

$$Porosity = 1 - (\frac{\rho_{(bulk)}}{\rho_{(true)}}) \quad (9)$$

Where, $\rho_{(bulk)}$: Bulk density of the extruded sample (g/cm^3)

$\rho_{(true)}$: True density of the extruded sample (g/cm^3).

2.2.7 Scanning Electron Microscopy (SEM)

Scanning electron microscope (400F Field Emission, QUANTA, Holland) located at the Middle East Technical University Central Laboratory was used for the analysis. Extruded samples were covered with 3 nm Au-Pd by using sputter coater (Polaron, Range, UK). Images were scanned by the scanning electron microscope (400F Field Emission, QUANTA, Holland).

2.2.8 Water Absorption Index (WAI) and Water Solubility Index (WSI)

Method from Anderson et al. (1969) was used with some modifications to determine water absorption index and solubility index. The extruded samples were

grinded (SCM- 2914, Sinbo, PRC) and then sieved through 212 micron mesh (200 M.M B.S, Endecotts Ltd, London). 1 gram of the ground extruded sample was dispersed in 6 mL of distilled water and this mixture was stirred at 300 rpm by using a magnetic stirrer (Wisd WiseStir SMHS-3, Daihan Scintific Co. Ltd., Korea) for 30 min at 30ºC temperature. Samples were put into centrifuge tubes which were preweighted (TP-214, Denver Instrument, Germany) before addition of samples. Tubes were centrifuged (2-16 KL, Sigma Laborzentrifugen, Germany) at 24ºC at 4000 g for 20 min. The supernatant that were poured into weighted petri dishes was weighted and put into an oven (Binder, Germany) at 110ºC for overnight. Water absorption index and water solubility index were calculated according to equations below.

$$WAI = \left(\frac{m_{sediment}}{m_{dry}}\right) \quad (10)$$

$$WSI = \left(\frac{m_{dissolved}}{m_{dry}}\right) * 100 \quad (11)$$

Where $m_{(dry)}$: Dry weight of extruded samples (g)

$m_{(sediment)}$:Weight of residue after pouring supernatant in the centrifuge tubes (g)

$m_{(dissolved)}$: Weight of supernatant in the petri dishes after drying process (g).

2.2.9 Color

The extruded samples were grinded (SCM- 2914, Sinbo, PRC) and then passed through a sieve (212 micron, 200 M.M B.S, Endecotts Ltd, London). The product was put into a glass holder and surface of product was smoothed. Color values were measured with a colorimeter (CR-10, Konica minolta, Japan) in terms of L*, a* and b* values which are lightness (brightness), redness and yellowness,

respectively. The colorimeter was calibrated against a white paper (L*= 93.8, a*= 0.0, b*= 5.2).

2.2.10 Texture

Hardness, maximum stress and fracturability of samples were measured by a texture analyzer (TA.XTPlus, Stable Micro Analyser, England). A force- time curve was used for all analyzes. Two different probes were used to determine hardness, maximum stress and fracturability.

Hardness was determined by measuring the peak force of the first breaking of samples. Maximum three and average of the maximum three hardness values were used for puncture probe tests. Fracturability was determined as the distance at break. Maximum stress was calculated by using eqn. 12 (Sahin & Sumnu., 2006)

$$\sigma = \frac{F*L}{\pi r^3} \qquad (12)$$

Where σ : Maximum stress (Mpa)
F : Force (N)
r : Radius of extruded samples (m)
L : Distance of two adjustable supports (m)

Height and force calibration of the texture analyzer (TA.XTPlus, Stable Micro Analyser, England) were done before texture analysis. The first probe was sharp blade probe which was 0.12cm thick and 8 cm wide. Cut tests were done by sharp blade probe. Extrudates of samples was cut 4 cm long and put on two adjustable supports. Distance of two adjustable supports was 2 cm. For three point bending test, the test speed, distance, trigger force were adjusted as 10.00 $mm.s^{-1}$, 10mm, 5.0 g respectively. Maximum stress and fracturability values were determined with

sharp blade probe. The second probe was puncture probe which was 2mm diameter. Extrudates were cut 2 cm long and put on the surface of the texture analyzer (TA.XTPlus, Stable Micro Analyser, England). The distance for puncture was adjusted as 2 mm. The test speed and trigger force were adjusted as 2 $mm.s^{-1}$ and 5.0 g, respectively. Hardness values of extruded samples were measured with puncture probe.

2.2.11 Sensory

2.2.11.1 Acceptance Test

Panelists from food engineering department at Middle East Technical University evaluated the extruded samples by using 9 point hedonic scale for their flavor, appearance, color, texture and overall acceptance. Three- digit random numbers were given to extruded samples and samples were served with equal amount in the plates. Panelists rinsed their mouths with water before and between tasting the samples.

2.2.11.2 Paired Comparison Test

Extrudates with microfluidized and non microfluidized onion skin were compared with the paired comparison test for their flavor, appearance, color, texture and overall acceptance. Before evaluation, these parameters were explained to 10 panelists from Food Engineering master students at Middle East Technical University and then panelists evaluated the extruded samples by using 9 point hedonic scale. Three- digit random numbers were given to two extruded samples and samples were served with equal amount in the plates. Panelists rinsed their mouths with water before and between tasting the samples. Paired comparison test (Kemp et al., 2009) was used for the analyses of data.

2.2.12 Statistical Analysis

The results were analyzed by one-way analysis of variance (ANOVA) to identify whether there was any significant difference between samples at $p \leq 0.05$. Tukey method was used when significant different was determined at $p \leq 0.05$ by using Minitab 16.1.1 Software.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Expansion Characteristics

Expansion and texture formation are related to viscoelastic characteristics of melt, plasticizing characteristics of water in transition, glassy state and also mechanism of bubble nucleation and growth (Altan & Maskan, 2012). Higher ratio of melt expansion is significantly attributed to higher starch content. For good expansion of melt, more than 60% starch content of dry basis formulation is necessary. In the study of Bouvier & Campanella, (2014), addition of particles of fibrous materials in continuous melt resulted in lower cell size, breaking cell walls of extrudates and causing a reduction of volumetric expansion.

Effects of using different ratio of microfluidized onion skins in extruded samples on physical properties were presented in Table 3. According to the results, addition of microfluidized onion skins to feed samples caused changes in sectional expansion index (SEI), volumetric expansion index (VEI), bulk density and porosity values ($p<0.05$). Where SEI, VEI and porosity values showed a decreasing trend while bulk density indicated an increasing trend with addition of microfluidized onion skins.

Table 3 Effect of microfluidized onion skins addition on physical properties of the extruded samples.

	SEI	VEI	Bulk Density (g/cm^3)	Porosity
0%mf onion skin	16.58 ± 3.55^{a}	11.60 ± 2.97^{a}	0.15 ± 0.02^{b}	0.91 ± 0.02^{a}
2%mf onion skin	11.67 ± 1.74^{b}	9.07 ± 2.27^{ab}	0.18 ± 0.05^{ab}	0.88 ± 0.03^{ab}
6%mf onion skin	8.10 ± 1.14^{c}	6.91 ± 1.90^{b}	0.23 ± 0.05^{a}	0.84 ± 0.05^{bc}
10%mf onion skin	6.78 ± 0.69^{d}	5.87 ± 1.07^{b}	0.26 ± 0.07^{a}	0.82 ± 0.04^{c}

SEI results are means ± SD (n= 100); VEI results are means ± SD (n= 6); Porosity results are means ± SD (n= 6); Bulk Density results are means ± SD (n= 6); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

The reason for the decrease in SEI, VEI, and porosity could be due to the increase in fiber content in the wheat flour melt. In addition, increasing bulk density values of extrudates were also due to addition of dietary fiber content.

There have been numerous studies about the effects of different fiber content addition to extrudates (Hsieh et al., 1989; Wang et al., 1993; Chang et al., 1998; Yanniotis et al., 2007; Altan et al., 2008a; Brennan et al., 2008). Hsieh et al. (1989) studied wheat fiber and oat fiber-containing corn meal extrudates. The increase in bulk density was obtained by increasing fiber content in both wheat fiber and oat fiber- containing corn meal extrudates. Moreover, Altan et al. (2008a) studied with barley- grape pomace blends. It was stated that increasing bulk density with increase in ratio of grape pomace may attribute to fiber content of feed. Furthermore, Chang et al. (1998) added jatobá flour into cassava starch and decreasing expansion of the products occurred due to increasing fiber content from jatobá flour.

Microfluidization process affects particle size of materials (Oberdörster et al., 2005; Sanguansri & Augustin, 2006). According to Wang et al. (2012), after microfluidization process, reduction of particle size could affect the hydration features of wheat brans. Increasing water holding capacity of wheat bran was occurred by changing particle size after passing through microfluidization process.

Comparison of addition of microfluidized and non-microfluidized onion skin to melt was presented in Table 4. According to Table 4, there was no significant difference between 6% microfluidized and non-microfluidized onion skins added samples in sectional expansion index (SEI), volumetric expansion index (VEI), bulk density and porosity values ($p<0.05$). Results indicate that microfluidized onion skin addition did not show significant difference from the non-microfluidized onion skin addition during extrusion process at this concentration.

Table 4 Comparison of microfluidized and non- microfluidized onion skin addition on physical properties of the extruded samples.

	SEI	VEI	Bulk Density (g/cm^3)	Porosity
6%mf onion skin	8.10 ± 1.14[a]	6.91 ± 1.90[a]	0.23 ± 0.05[a]	0.84 ± 0.05[a]
6% not mf onion skin	8.32 ± 1.32[a]	8.12 ± 1.70[a]	0.21 ± 0.07[a]	0.87 ± 0.03[a]

SEI results are means ± SD (n= 100); VEI results are means ± SD (n= 6); Porosity results are means ± SD (n= 6); Bulk Density results are means ± SD (n= 6); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

3.2 Scanning Electron Microscopy

In Figure 4, decreasing porosity of extrudates by increasing microfluidized onion skin content in the extrudates was observed. Due to fiber addition, a decrease in porosity of extrudates was clearly seen by scanning electron microscopy (SEM) (Figure 4).

One of the main reasons for different porosity of extruded samples may be due to increasing addition of dietary fiber to wheat flour. Jin et al. (1995) studied increasing fiber content to corn meal melt which caused to less expanded extrudates with small air size and thicker cell walls.

Figure 5 illustrates the comparison of 6% microfluidized and non-microfluidized onion skin added samples. Similar images were obtained for the samples which correlates with the porosity values (Table 4).

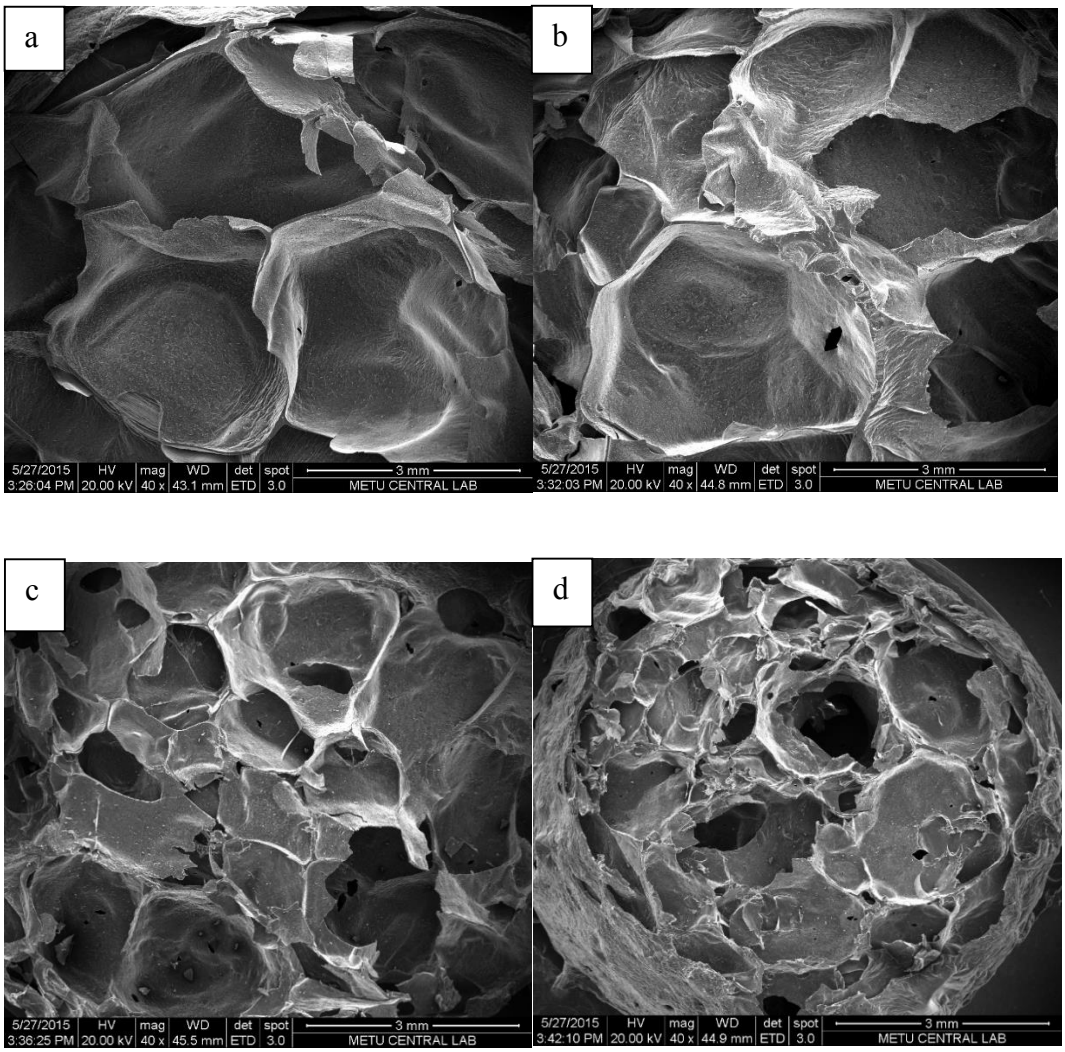

Figure 4 Scanning electron microscopy images of extrudates with 40X magnification A) Control sample B) 2% microfluidized onion skin added sample C) 6% microfluidized onion skin added sample D) 10% microfluidized onion skin added sample.

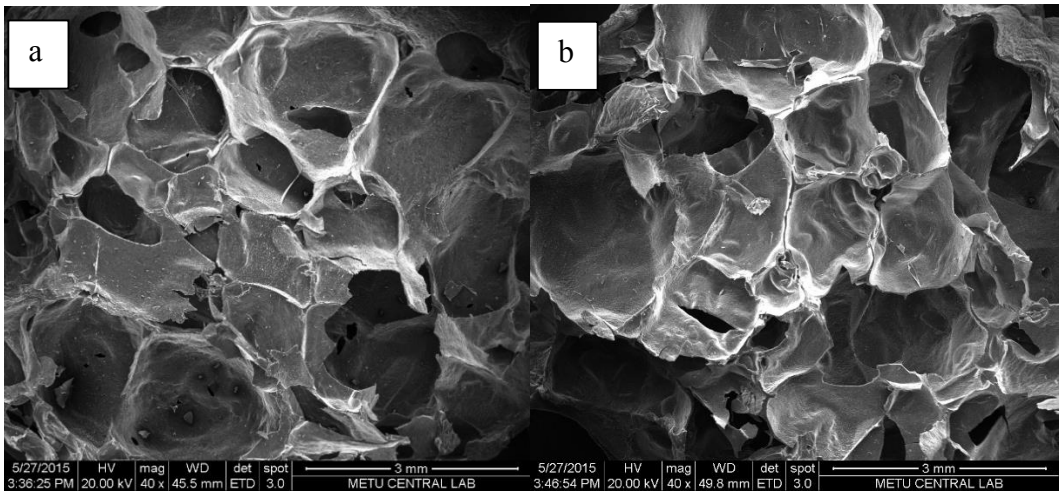

Figure 5 Scanning electron microscopy images of extrudates with 40X magnification A) 6% microfluidized onion skin added sample B) 6% non microfluidized onion skin added sample.

3.3 Water Absorption Index and Water Solubility Index

Water absorption index (WAI) values show volume occupied by granule or starch polymer after swelling in excess water (Sriburi & Hill, 2000). Moreover, WAI could be considered as measurement of amount of intact and fully gelatinized starch granules (Zhu et al., 2010). Water solubility index (WSI) values show amount of free polysaccharide or polysaccharide released from granule after addition of excess water (Sriburi & Hill, 2000). Furthermore, WSI could be considered as degree of starch degradation (Zhu et al., 2010).

Effects of different ratio of microfluidized onion skins in extruded samples on WAI and WSI were presented in Table 5. According to the results, addition of microfluidized onion skins to feed samples caused no significant changes in WAI and WSI ($p<0.05$).

Numerous studies were investigated to understand the effect of fiber addition to extrudates on WAI and WSI values (Artz et al., 1990; Jin et al., 1995; Chang et al., 1998; Altan et al., 2008b; Stojceska et al., 2008). According to Jin et al. (1995), decrease in WAI and increase in WSI of extrudates were observed when fiber content increased from 0% to 20% in corn meal. However, by more fiber content to melt, these trends were reversed for extrudates. Moreover, similar results have been reported by Altan et al. (2008b) in the study with tomato pomace into barley flour. They concluded that decreasing in starch content and competition of absorption of water between tomato pomace and available starch caused that result. According to Stojceska et al. (2008), addition of cauliflower, which had high protein and fibre content, to melt, WAI of extrudates had positively correlated with fibre content, on the other hand, WSI of extrudates was not significantly affected. Artz et al. (1990) found increasing fiber content to melt resulted in reverse relationship for water holding capacity in other words, increasing fiber concentration caused a decrease in WAI of extrudates. The reason might be greater water holding capacity of gelatinized corn starch when compared with hemicellulose or cellulose, main component of corn fiber. The study of Chang et al. (1998) showed increased values of WAI while increasing the concentration of jatobá flour into cassava starch at high moisture. In the study, protein denaturation, starch gelatinization and swelling of fiber were attributed to increase in WAI of extrudates.

Table 5 Effect of microfluidized onion skins addition on water absorption index (WAI) and water solubility index (WSI) values of extruded samples.

	WAI ($g.g^{-1}$)	**WSI (%)**
0%mf onion skin	3.02 ± 0.10^{a}	34.49 ± 3.16^{a}
2%mf onion skin	3.14 ± 0.22^{a}	33.26 ± 2.36^{a}
6%mf onion skin	3.12 ± 0.22^{a}	30.19 ± 3.5^{a}
10%mf onion skin	3.05 ± 0.16^{a}	31.37 ± 1.69^{a}

WAI and WSI results are means ± SD (n= 8); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

Microfluidization affects water holding capacity of materials and also structure of materials (Chau et al., 2006; Chau et al., 2007; Wang et al., 2012). According to Wang et al (2012), water holding capacity was increased, this situation might be

attributed to reduction of particle size after microfluidization process. As a result of increasing surface area and improving solubilization of protein and cell wall pectin substances might cause the increasing solubility of carrot insoluble fibre rich fraction. Moreover, as reduction particle size by milling procedure, starch in the sample may alter (Sriburi & Hill, 2000). Increasing starch conversion may attributed to increase WAI and maximum values of WAI could be seen at particular quantity of starch conversion (Sriburi & Hill, 2000).

Gelatinization could be affected by addition of non-starch polysaccharide ingredients. Yanniotis et al. (2007) explained water acts like a plasticizer of amorphous regions of starch granules and also improve rupture of hydrogen bonds so new hydrogen bonds occurred between itself and starch chains were associated. On the other hand, pectin had capacity to hydrate so availability of water for gelatinization process was restricted.

Comparison of addition of microfluidized and non-microfluidized onion skin to melt was presented in Table 6. According to the results, there was no significant difference between 6% microfluidized and 6% non-microfluidized onion skin added samples in water absorption index (WAI), water solubility index (WSI).

Having no significant difference in WAI and WSI of the samples with addition of microfluidized onion skin could be that concentration of onion skins were not enough to show the difference.

Table 6 Comparison of microfluidized onion skin addition and onion skin addition on water absorption index (WAI) and water solubility index (WSI) values of the extruded samples

	WAI ($g.g^{-1}$)	WSI (%)
6%mf onion skin	3.12 ± 0.22^a	30.19 ± 3.5^a
6% not mf onion skin	3.09 ± 0.25^a	34.29 ± 4.84^a

WAI and WSI results are means ± SD (n= 8); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$)

3.4 Color

One of the important characteristics of extruded samples is color change which could inform about the extent of browning reactions, degree of extrusion cooking and degradation of pigment of melt occurring during extrusion cooking (Altan et al., 2008a). According to Chessari & Sellahewa, (2001) formation of colors and flavours in the extrusion process rely on maillard reaction.

Addition of microfluidized onion skin caused reduction of lightness values (L*), increase in redness values (a*) and yellowness values (b^*) of extruded samples due to distinct color of onion skin (Table 7).

L* value shows lightness (brightness), a* value shows redness and b* value shows yellowness. Results indicated the a^*, b* values of samples were affected by addition of microfluidized onion skin (Table 8).

Table 7. Effect of microfluidized onion skins addition on color properties of extruded samples

	L^*	a^*	b^*
0%mf onion skin	77.97 ± 4.77^{a}	3.69 ± 1.76^{d}	17.77 ± 0.77^{c}
2%mf onion skin	66.11 ± 3.53^{b}	10.76 ± 0.73^{c}	20.15 ± 0.81^{b}
6%mf onion skin	54.7 ± 2.46^{c}	14.76 ± 1.88^{b}	21.93 ± 1.85^{a}
10%mf onion skin	46.76 ± 2.13^{d}	17.08 ± 2.30^{a}	20.99 ± 1.98^{ab}

L*,a*,b* results are means ± SD (n= 20); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

Table 8 shows the comparison of microfluidized and non - microfluidized onion skin added samples. In terms of lightness, there was no significant differences while redness and yellowness values indicates slight differences ($p \leq 0.05$). This could be related to color of microfluidized onion skin which had more redness and yellowness due to microfluidization process.

Numerous studies show that particle size reduction affects the color of the samples (Prasopsunwattana et al., 2009; Mert, 2012; Öztürk, 2014). According to Prasopsunwattana et al. (2009), particle size reduction might be attributed to the visibility of the tannins present in the whole barley flour which have different particle size in 131 μm (intermediate) and 68 μm (micro ground). Furthermore, according to Öztürk (2014), caratenoids in zein are lutein and zeaxanthin, these caratenoids have effect of yellow color of samples. After microfludization process, due to revailing of the caratenoids, more yellowish sample obtained. Moreover, after microfluidization process, total color change of ketchup was affected (Mert, 2012).

Table 8. Comparison of microfluidized and non - microfluidized onion skin addition on color properties of the extruded samples

	L^*	a^*	b^*
6% mf onion skin	54.7 ± 2.46^a	14.76 ± 1.88^b	21.93 ± 1.85^b
6% not mf onion skin	54.43 ± 1.58^a	15.94 ± 0.53^a	$23,28 \pm 1.23^a$

L*,a*,b* results are means ± SD (n= 20); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

3.5 Texture

Low values of fracturability and hardness are desirable for snacks (Altan, 2008b). More force required to break down sample was associated with higher value of maximum peak in other words higher value of hardness value of sample (Sawant et al. 2013).

Cut tests and puncture tests were used to determine the hardness and the fracturability values of the extruded products.

3.5.1 Cut Tests

Figure 6 and 7 shows the maximum stress and fracturability values that were obtained by the sharp blade probe. Data indicates that addition of microfluidized onion skin increased maximum stress and decreased fracturability.

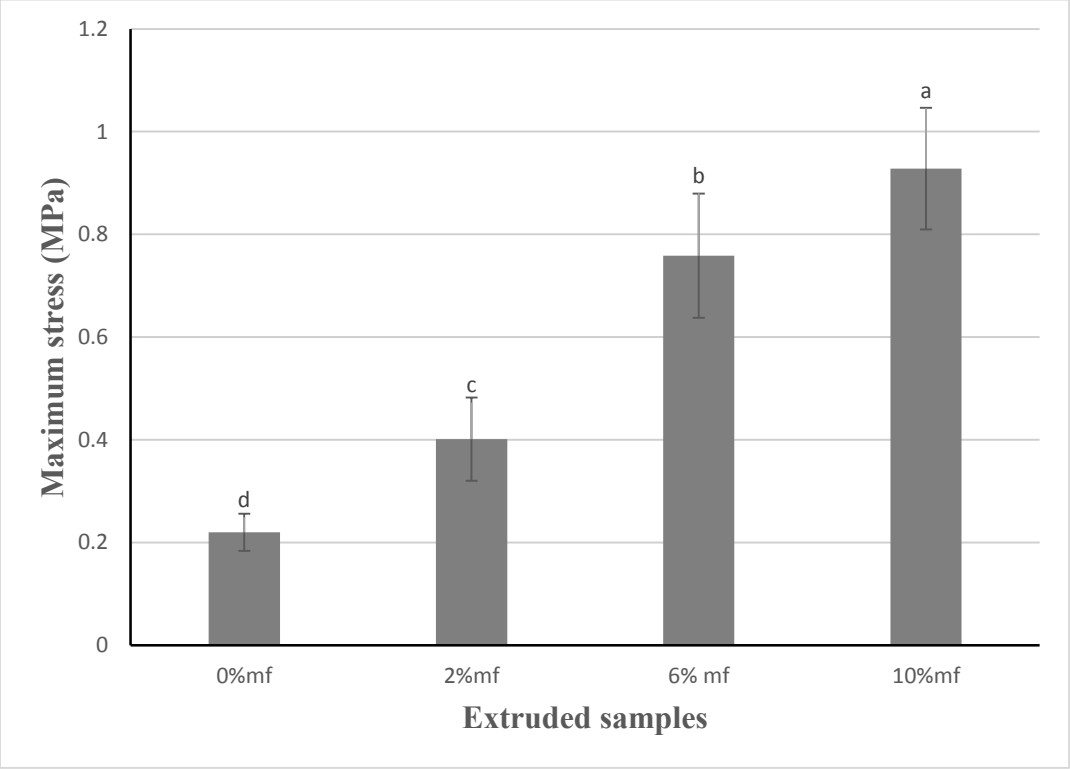

Figure 6 Effect of microfluidized onion skin addition on maximum stress of extruded samples (measured with the sharp blade probe). Results are means ± SD (n= 10).

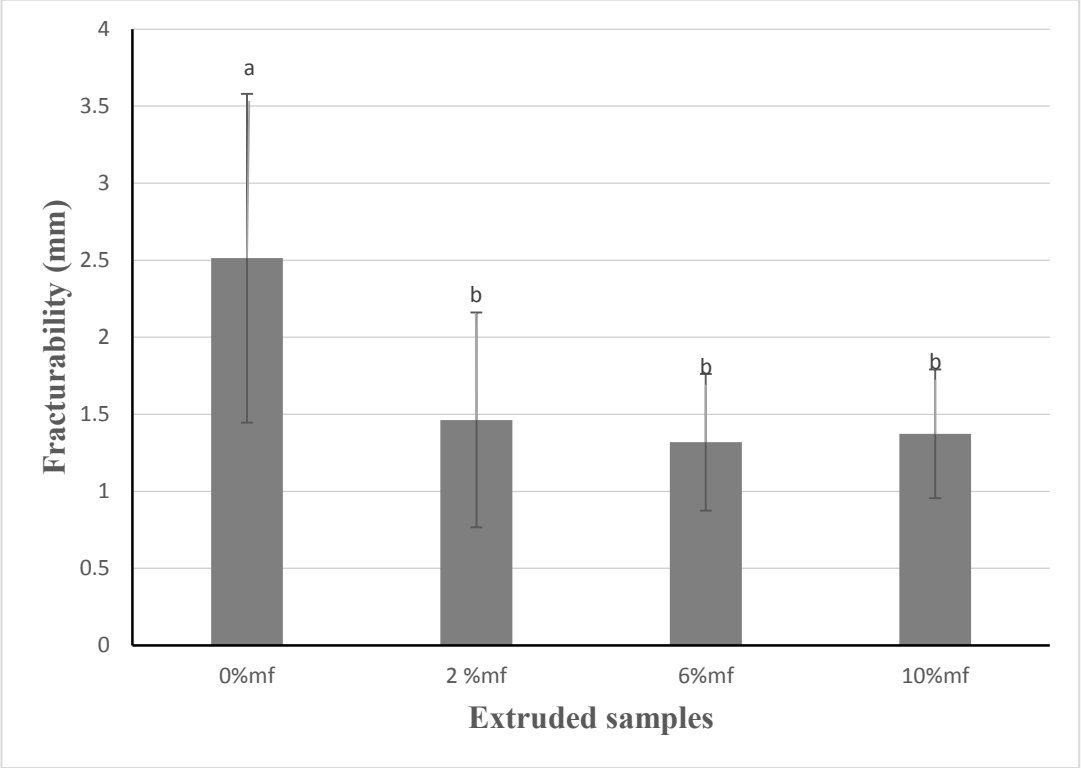

Figure 7 Effect of microfluidized onion skin addition on fracturability of extruded samples (measured with the sharp blade probe). Results are means ± SD (n= 10).

Comparison of maximum stress and fracturability values of microfludizied and non- microfluidized onion skin added samples indicates no significant difference when measured with the sharp blade probe (Figure 8 and Figure 9).

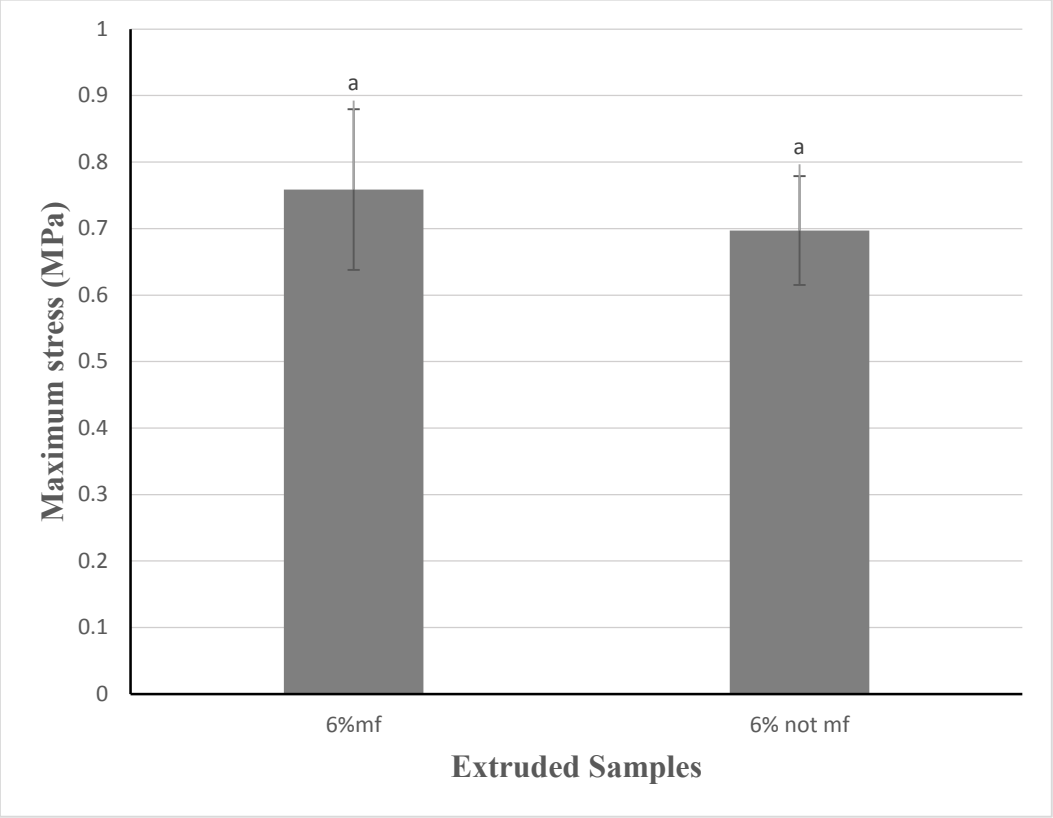

Figure 8 Comparison of microfluidized onion skin and non - microfluidized onion skin addition on maximum stress of the extruded samples (measured with the sharp blade probe). Results are meants ± SD (n=10).

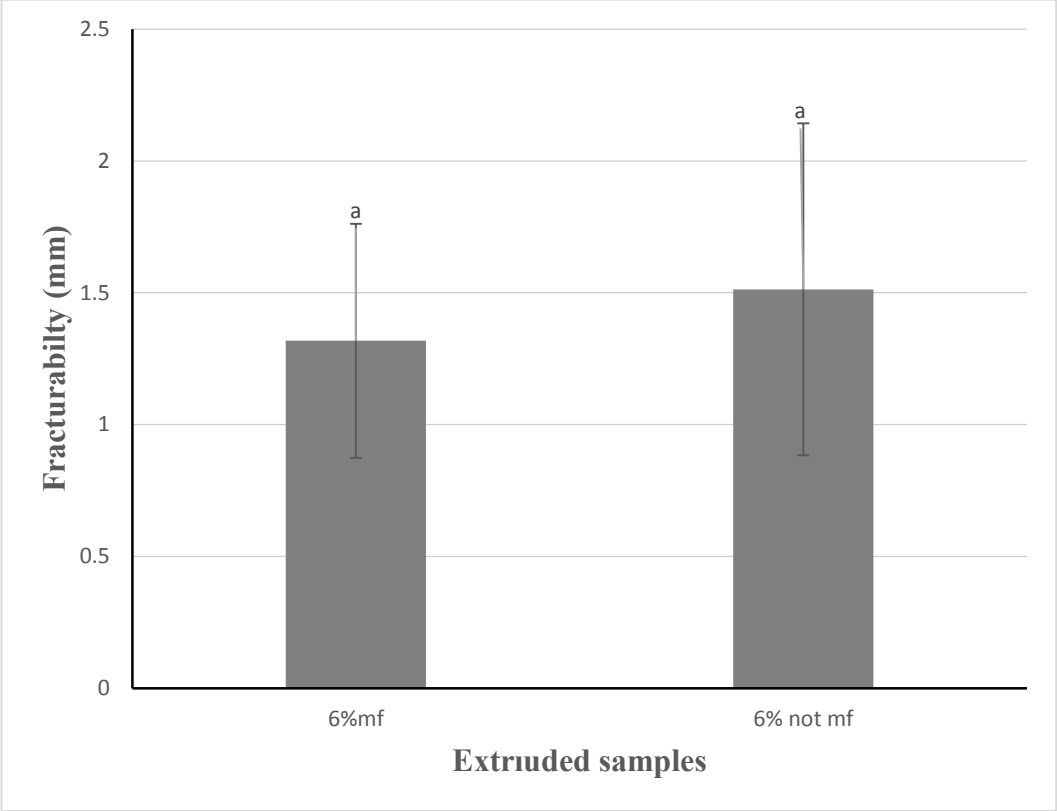

Figure 9 Comparison of microfluidized onion skin and non - microfluidized onion skin addition on fracturability of the extruded samples (measured with the sharp blade probe) . Results are meants ± SD (n=10).

3.5.2 Puncture Tests

Hardness values of the samples were measured by using the height of the first peak, defined as peak force (Ding et al., 2006). There are many effects on changing hardness values of samples such as average cell size, cell size distribution, cell wall thickness and mechanical features of the cell wall of samples (Gibson & Ashby, 1988).

Maximum three hardness values were measured. Figure 10, 11 and 12 show the three maximum hardness values for the samples. Figure 13 shows the average of those three values. Hardness values increased with increasing microfludizied onion skin content.

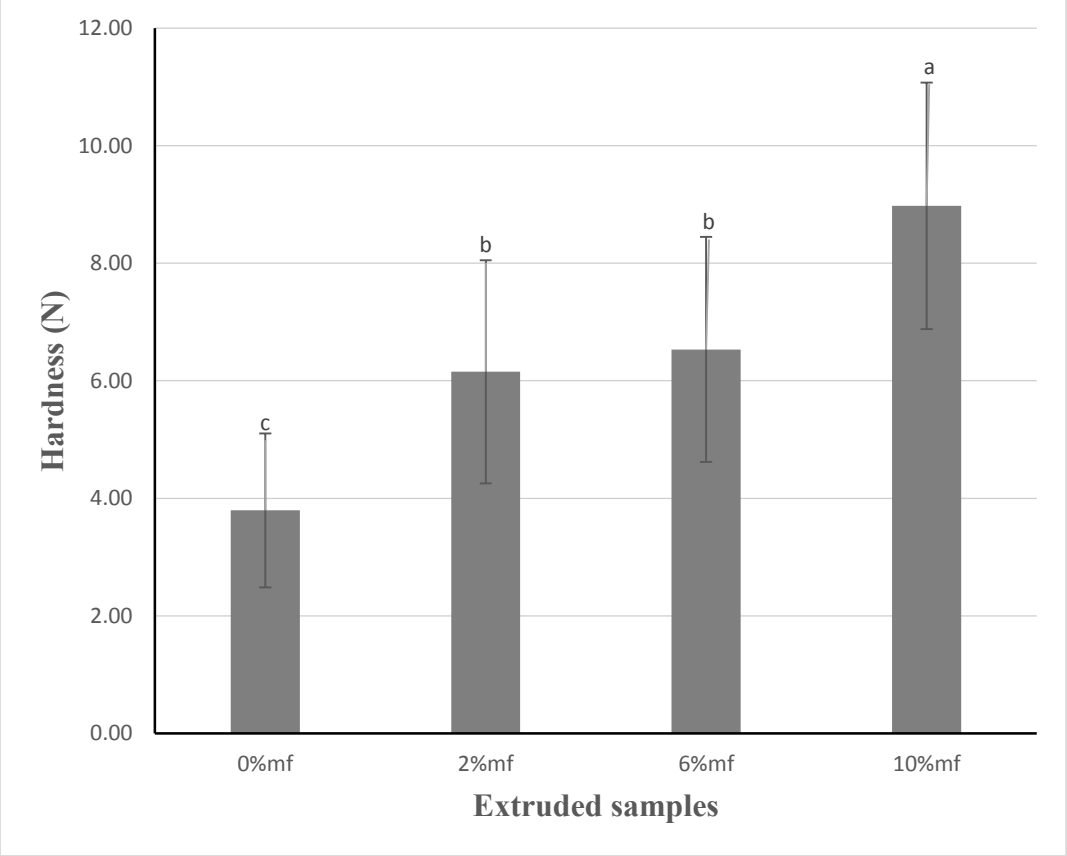

Figure 10 Effect of microfluidized onion skins addition on the first highest hardness values of extruded samples (measured with the puncture probe). Results are means ± SD (n= 20).

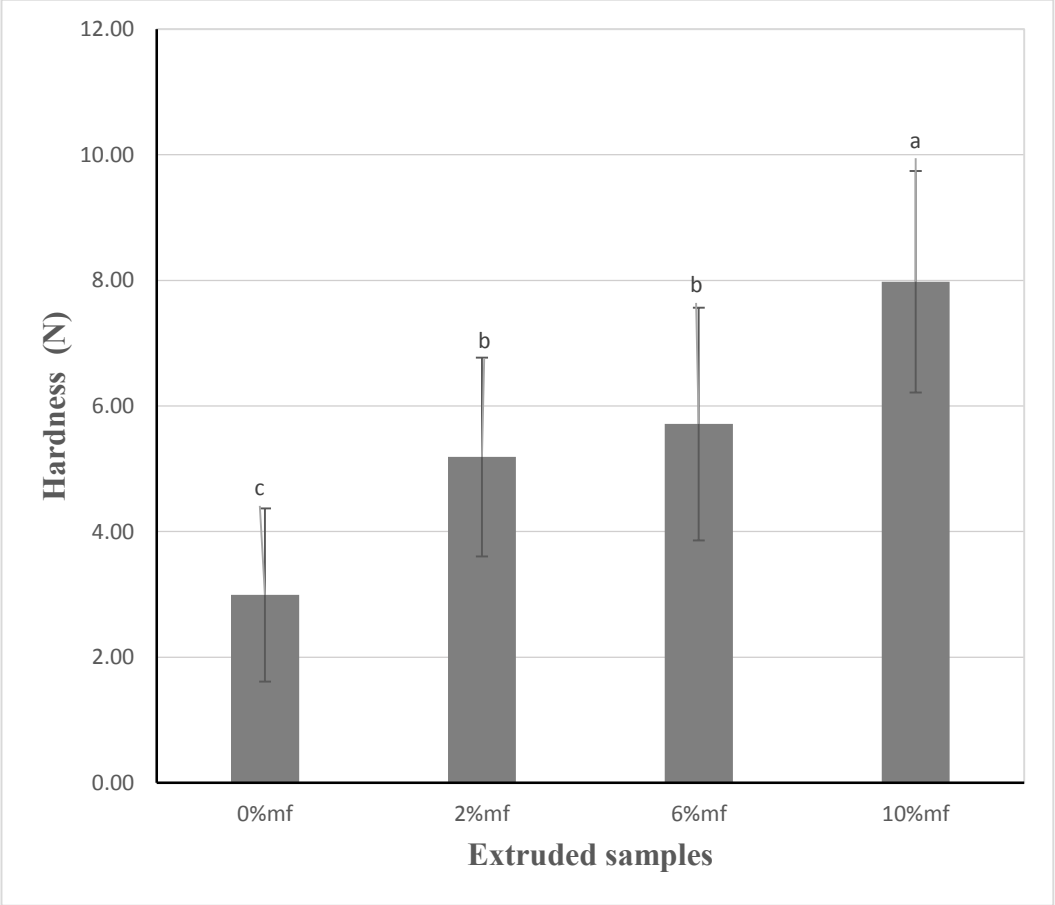

Figure 11 Effect of microfluidized onion skins addition on the second highest hardness values of extruded samples (measured with the puncture probe). Results are means ± SD (n= 20).

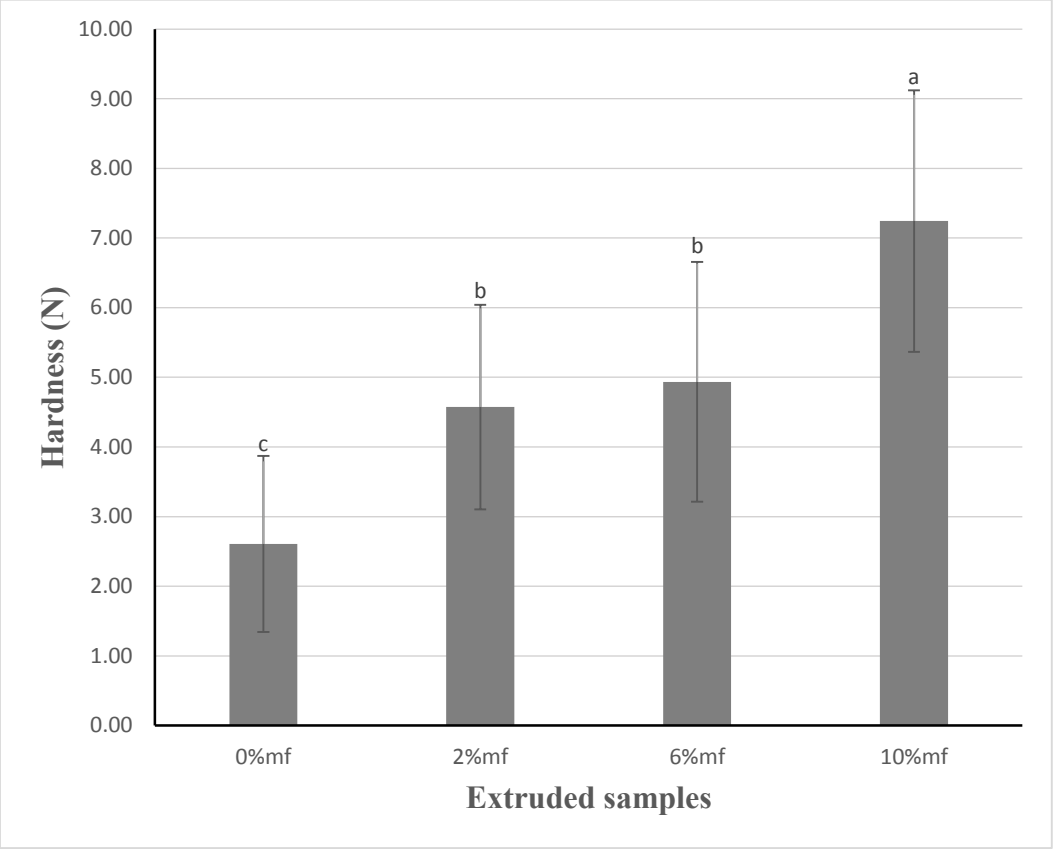

Figure 12 Effect of microfluidized onion skins addition on the third highest hardness values of extruded samples (measured with the puncture probe). Results are means ± SD (n= 20).

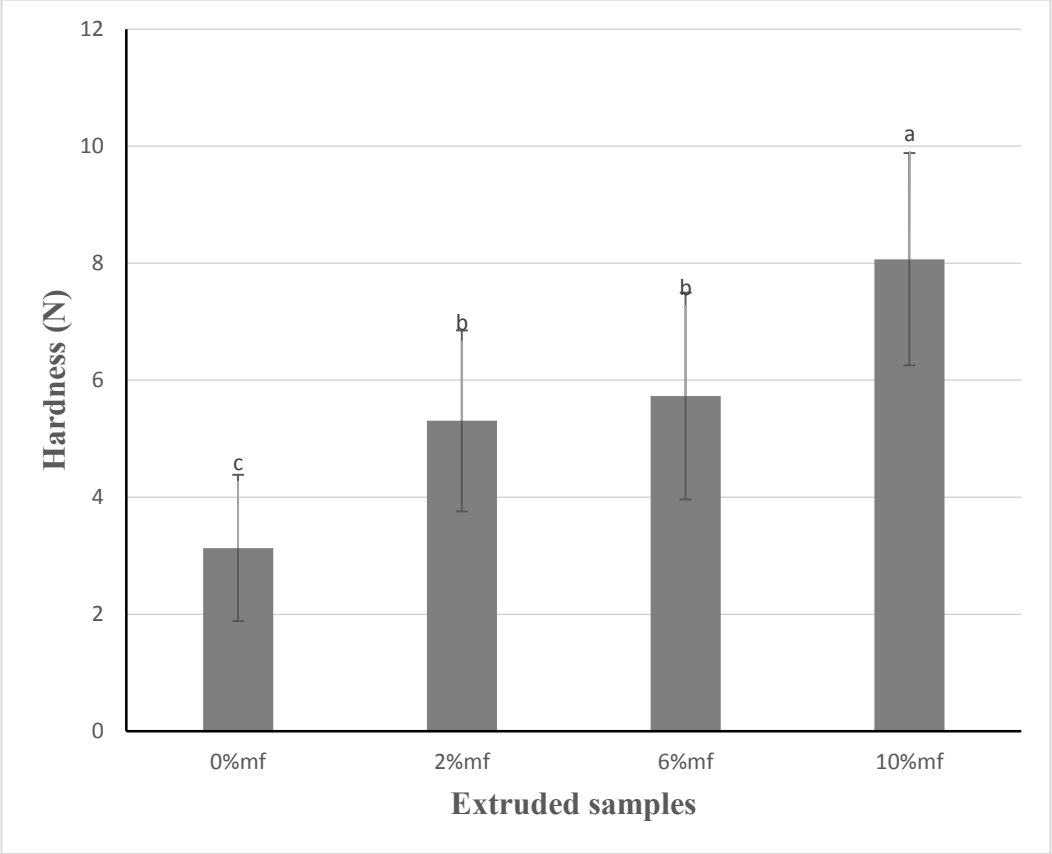

Figure 13 Effect of microfluidized onion skins addition based on the average of maximum three hardness values of extruded samples (measured with the puncture probe). Results are means ± SD (n= 20).

Due to higher bulk density, less expansion and smaller cell size, increased hardness was expected with increased concentration of microfludizied onion skin addition. In Hsieh et al. (1989), increasing breaking force for extrudates was attributed to increase in bulk density, decrease radial expansion while adding fiber content in corn meal. Furthermore, study of Jin et al. (1995) showed increasing breaking strength of extrudates that is attributed to increasing fiber content and sugar content

to corn meal. Increasing grape pomace content in barley flour increased brittleness in the extrudates (Altan et al., 2008b).

Effects of soluble and insoluble dietary fiber addition to melt could indicate different results for extruded products (Yanniotis et al., 2007; Stojceska et al., 2008; Brennan et al., 2008a). According to Yanniotis et al. (2007), with increasing wheat fiber content as insoluble dietary fiber content, hardness increased and porosity decreased. With addition of pectin as soluble dietary fiber to corn melt, hardness decreased and porosity increased. This result might be attributed to effect of these contents on cell wall thickness because fibers which had less porous matrix caused to thicker cell wall and also harder extrudates. Stojceska et al. (2008) reported that the total cell area decreased whereas the wall thickness of cells increased while increasing level of cauliflower by products into wheat based extrudates. A study of Brennan et al. (2008) showed significantly higher hardness value of extrudates comparing with control sample with addition of bran to wheat melt. On the other hand, addition of inulin to wheat melts caused significantly smaller hardness value of extrudates comparing with control sample. On the other hand, addition of Hi-maize, guar gum and swede fiber to wheat melt did not significantly affect hardness value comparing with hardness value of control sample.

Comparison of microfludizied and non- microfludizied onion skin addition for hardness values with the puncture probe were shown in Figure 14 through Figure 17. Data indicates that there is no significant difference for hardness values for microfludizied and non-microfludizied onion skin added samples.

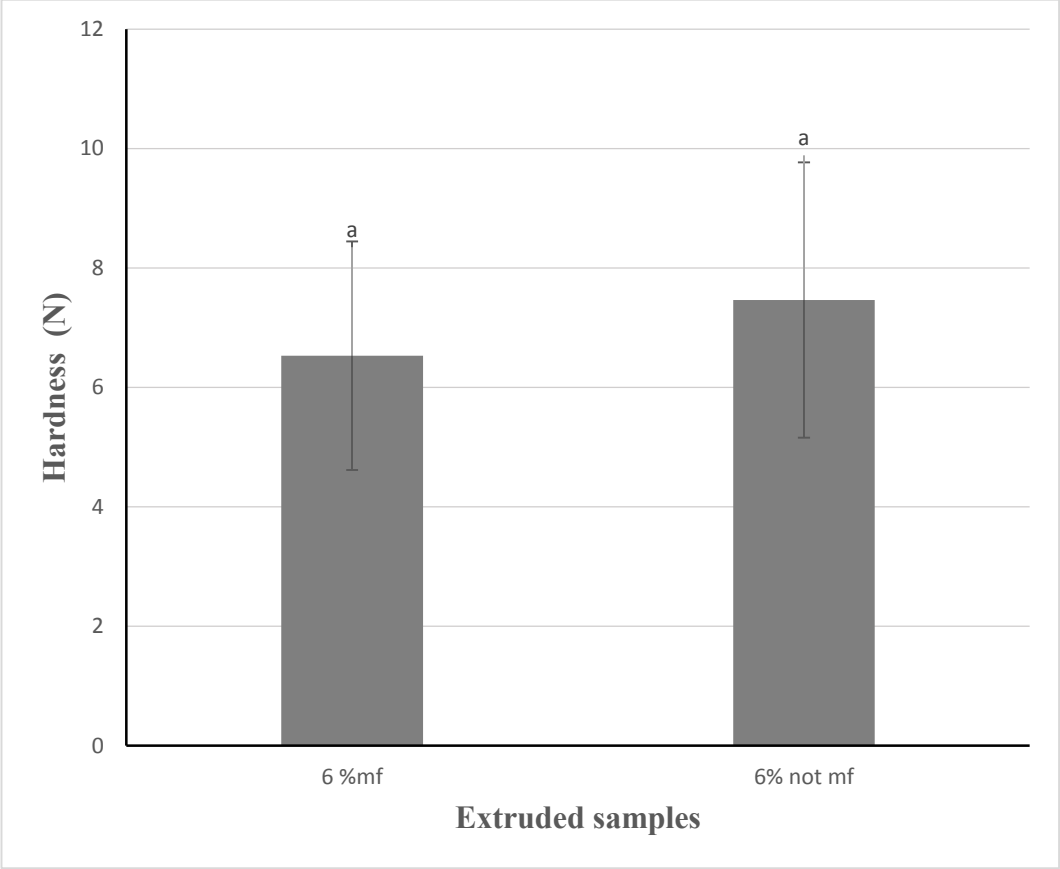

Figure 14 Comparison of microfluidized onion skin and non - microfluidized onion skin addition on the first highest hardness values of the extruded samples (measured with the puncture probe). Results are means ± SD (n=20).

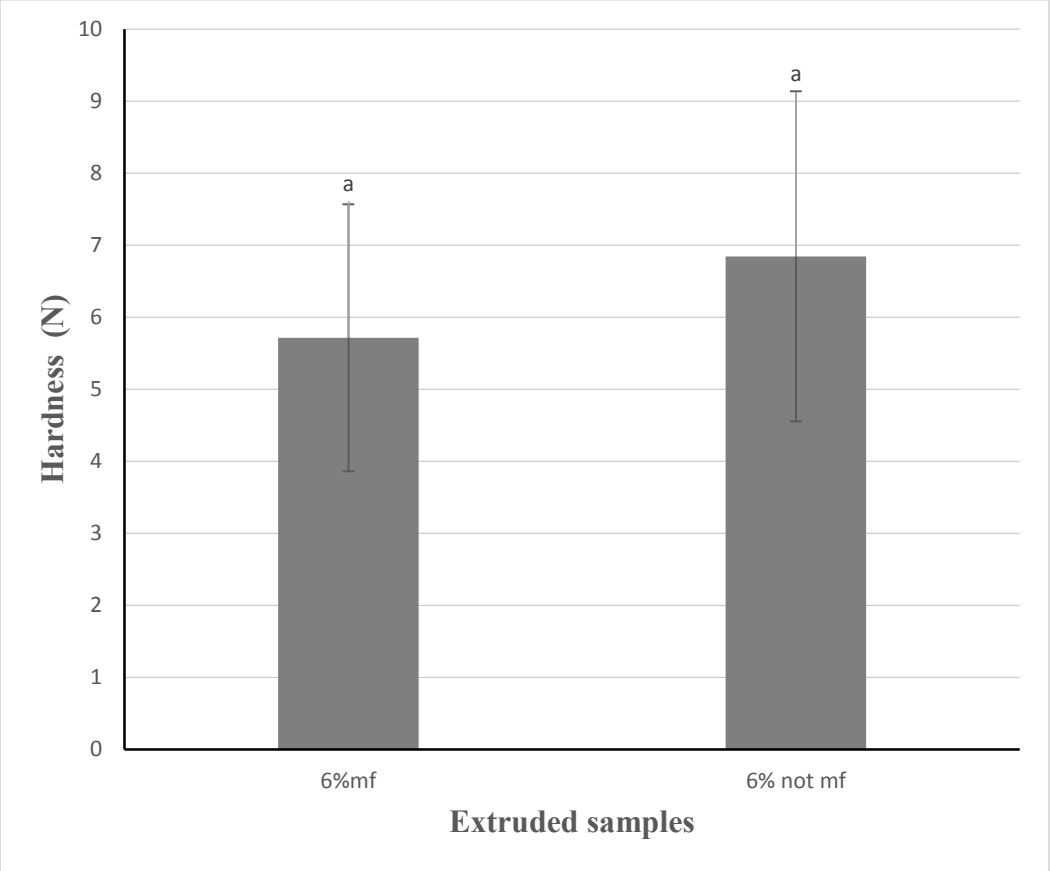

Figure 15 Comparison of microfluidized onion skin and non - microfluidized onion skin addition on the second highest hardness values of the extruded samples (measured with the puncture probe). Results are means ± SD (n=20).

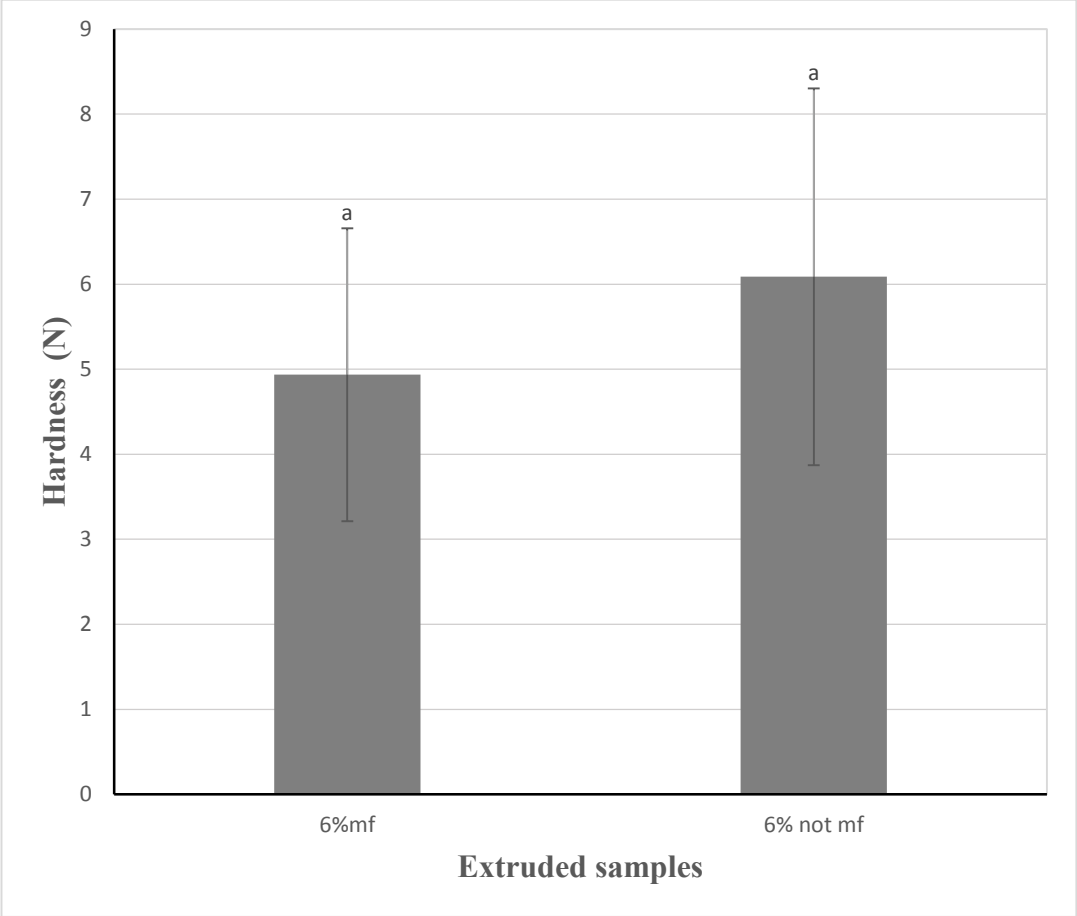

Figure 16 Comparison of microfluidized onion skin and non - microfluidized onion skin addition on the third highest hardness values of the extruded samples (measured with the puncture probe). Results are means ± SD (n=20).

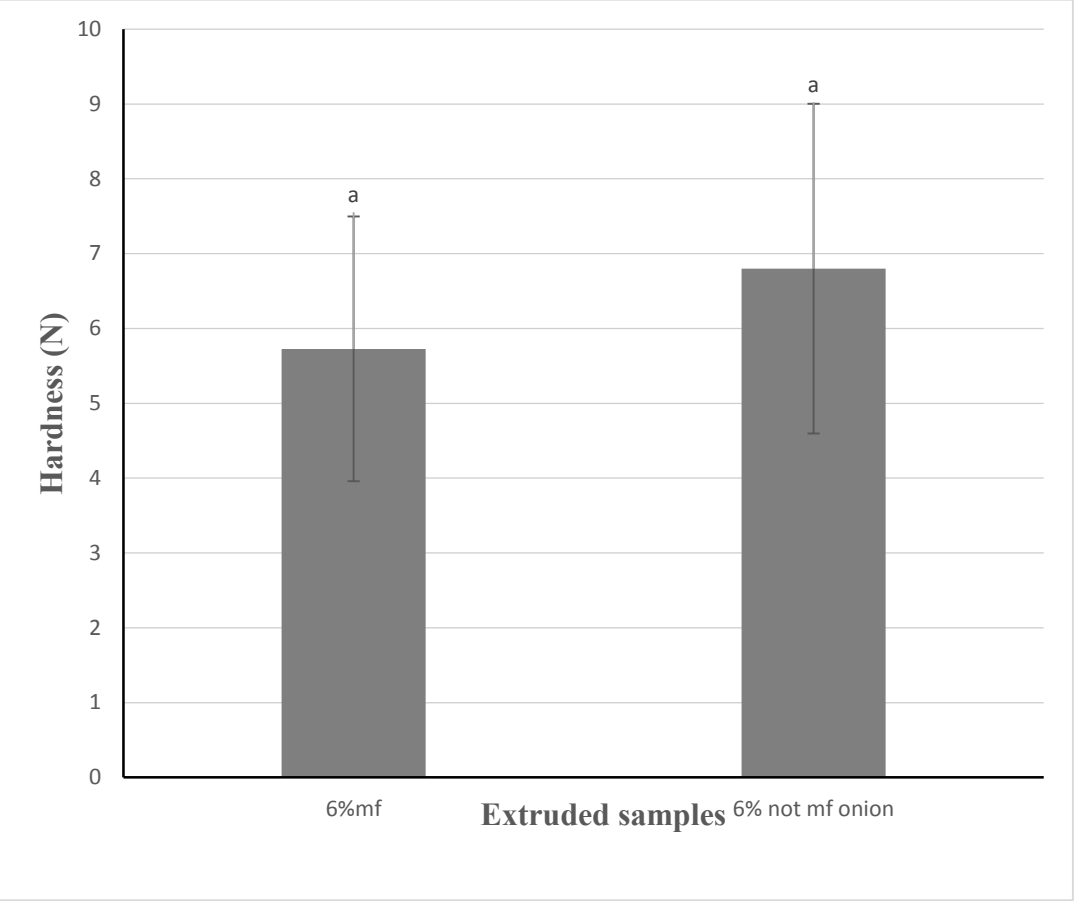

Figure 17 Comparison of microfluidized onion skin and non - microfluidized onion skin addition based on the average of maximum three hardness values of the extruded samples (measured with the puncture probe). Results are means ± SD (n=20).

3.6 Sensory Analysis

3.6.1 Acceptance Test

For sensory analysis 8 panelists scored the samples by hedonic scale. Table 10 illustrates increasing microfluidization onion skin content resulted in significantly decreasing values for appearance, texture, color, flavor, overall acceptance ($p \leq 0.05$). From the results, it could be concluded that microfludizied onion skin addition, was detectable after 2% microfluidized onion skin addition.

3.6.2. Paired Comparison Test

For a paired comparison test 10 panelists analyzed the extrudates with the 6% microfluidized onion skin and with 6% non - microfluidized onion skin. From the table of critical values table for paired comparison and paired difference test (two tailed), for 10 panelists, the minimum number to determine difference between preferences of extruded sample is 9 at p=0.05 (Kemp et al., 2009).

The results of appearance of extruded samples of preferences showed that 2 out of 10 panelists selected 6 % microfluidized onion skin to 6 % non - microfluidized onion skin added samples. Depending on table of critical values table for paired comparison and paired difference test (two tailed) (Kemp et al., 2009), there was no significant difference in appearance between the samples (p=0.05). Those numbers were 5, 5, 4 and 4 to 10 for texture, color, flavor and overall acceptance preferences, respectively. Depending on table of critical values table for paired comparison and paired difference test (two tailed)(Kemp et al., 2009), there were no significant differences in terms of appearance, texture, color, flavor and overall acceptance preferences between the microfluidized and non microfludized onion skin added samples (p=0.05).

Table 9 Effect of microfluidized onion skins addition on sensory analysis of extruded samples

	Appearance	Texture	Color	Flavor	Overall Acceptance
0%mf onion skin	8.19±0.96^{a}	7.81±0.94^{a}	7.88±1.27^{a}	7.56±1.37^{a}	7.81±1.10^{a}
2%mf onion skin	7.19±1.00^{a}	7.44±0.94^{ab}	7.63±1.43^{ab}	7.00 ±1.20^{ab}	7.00±1.46^{ab}
6%mf onion skin	5.56±1.61^{b}	5.75±1.1^{b}	5.63±1.53^{bc}	5.81 ±1.60^{ab}	5.31±1.33^{b}
10%mf onion skin	4.56±0.78^{b}	5.56±1.66^{b}	5.13±1.75^{c}	5.44 ± 1.59^{b}	5.25±1.60^{b}

Results are means ± SD (n= 8); values of the same column, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Addition of microfluidized onion skin caused a decrease in SEI, VEI and porosity while causing an increase in bulk density. Color values (L^*, a^*, b^*) were also affected with microfluidized onion skin addition. WAI and WSI data indicated no significant difference by addition of microfluidized onion skin. Hardness measured with the puncture probe and maximum stress measured with the sharp blade probe increased with addition of microfluidized onion skin while fracturability measured with the sharp blade probe indicated a decreasing trend with increasing the concentration of microfluidized onion skin. Sensory data indicated that microfluidized onion skin addition was detectable after 2% addition.

Comparison of microfluidized to non-microfluidized onion skin addition at 6% showed no significant difference for all the measured properties (SEI, VEI, porosity, bulk density, hardness, maximum stress, fracturability and sensory data) except in redness and yellowness values.

Results indicate that microfluidized or non microfluidized onion skin could be added to sample at low concentrations to increase the fiber content slightly.

For future study, the effect of two pass microfluidization process on the quality parameters of extrudates can be investigated.

REFERENCES

AACC, (1999). A historical perspective on defining dietary fiber, American Association of Cereal Chemists, CFW.

Akdogan, H. (1999). Review: High moisture food extrusion. *International Journal of Food Science and Technology*, *34*(3), 195- 207.

Altan, A., McCarthy, K. L., & Maskan, M. (2008a). Evaluation of snack foods from barley-tomato pomace blends by extrusion processing. *Journal of Food Engineering*, *84*(2), 231-242.

Altan, A., McCarthy, K. L., & Maskan, M. (2008b). Twin-screw extrusion of barley-grape pomace blends: Extrudate characteristics and determination of optimum processing conditions. *Journal of Food Engineering*, *89*(1), 24-32.

Altan, A., & Maskan, M. (2012). *Advances in food extrusion technology*. (pp. 132). Boca Raton, FL: CRC Press.

Alvarez-Martinez, L., Kondury, K. P., &Harper, J. M. (1988). A general model for expansion of extruded products. *Journal of Food Science*, *53*(2), 609-615.

Anderson, R. A., Conway, H. F., Pfeifer, V. F., & Griffin, E. L. (1969). Gelatinization of corn grits by roll and extrusion cooking. *Cereal Science Today*, *14*, 372-376.

Anderson, J. W., Baird, P., Davis Jr, R. H., Ferreri, S., Knudyson, M., Koraym A., Waters, V., & Williams, C. L. (2009). Health benefits of dietary fiber. *Nutrition Reviews*, *67*(4), 188- 205.

Artz, W. E., Warren, C., & Villota, R. (1990). Twin- screw extrusion modification of a corn fiber and corn starch extruded blend. *Journal of Food Science*, *55*(3), 746-750.

Barrett, A. M., & Peleg, M. (1992). Cell size distributions of puffed corn extrudates. *Journal of Food Science, 57*(1), 146- 148.

Benítez, V., Mollá, E., Martin- Cabrejas, M. A., Aguilera, Y., López- Andréu, F. J., & Esteban, R. M. (2011). Effect of sterilization on dietary fibre and physicochemical properties of onion by- products. *Food Chemistry*, *127*(2), 501-507.

Bouvier, J-M. & Campanella O. S. (2014). *Extrusion processing technology: Food and non- food biomaterials* (pp 11-37). Wiley Blackwell.

Brennan, M. A., Monro, J. A., & Brennan, C. S. (2008). Effect of inclusion of soluble and insoluble fibres into extruded breakfast cereal products made with reverse screw configuration. *International Journal of Food Science & Technology, 43*(12), 2278- 2288.

Chang, Y. K., Silva, M. R., Gutkoski, L. C., Sebio, L., & Da silva, M. A. A. P. (1998). Development of extruded snacks using jatobá (*Hymenia stigonocarpa* Mart) flour and cassava starch blends. *Journal Science Food Agriculture, 78*(1), 59-66.

Chau, C.F., Wen, Y. L, & Wang, Y. T. (2006). Effects of micronization on the characteristics and physicochemical properties of insoluble fibres. *Journal of the Science of Food and Agriculture, 86*(14), 2380- 2386.

Chau, C. F., Wang, Y. T., & Wen, Y. L. (2007). Different micronization methods significantly improve the functionality of carrot insoluble fibre. *Food Chemistry*, *100*, 1402–1408.

Chen, J., Liang, R-H., Liu, W., Liu, C-M., Li, T., Tu, Z-C., & Wan, J. (2012). Degradation of high-methoxyl pectin by dynamic high pressure microfluidization and its mechanism. *Food Hydrocolloids*, *28*(1), 121-129.

Chessari, C. J., & Sellahewa, J. N. (2001). Chapter 5 Effective Process Control. In: R. Guy, *Extrusion Cooking: Technologies and Applications*, (pp. 88-90), Cambridge: Woodhead Publishing Limited & CRC Press LLC.

Choi, I. S., Cho, E. J., Moon, J-H., & Bae, H-J. (2015). Onion skin waste as a valorization resource for the by-products quercetin and biosugar. *Food chemistry, 188*, 537- 542.

Ciron, C. I. E., Gee, V. L., Kelly, A. L., & Auty, M. A. E. (2010). Comparison of the effects of high-pressure microfluidization and conventional homogenization of milk on particle size, water retention and texture of non-fat and low-fat yoghurts. *International Dairy Journal*, *20* (5), 314-320.

Ciron, C. I. E., Gee, V. L., Kelly, A. L., & Auty, M. A. E. (2011). Effect of microfluidization of heat-treated milk on rheology and sensory properties of reduced fat yoghurt. *Food Hydrocolloids*, *25*, 1470-1476.

Codex Alimentarius. (2009). Guidelines for use of nutrition and health claims.

Cook, E. J., & Lagace, A. P. (1987). USA Patent No. US4908154-A.

Çıkrıkcı, S. (2013). Production of micro and nano fibers from hazelnut skin and utilization in cakes. MS Thesis, METU, Ankara.

Dalgleish, D. G., Tosh, S. M., & West, S. (1996). Beyond homogenization: The formation of very small emulsion droplets during the processing of milk by a microfluidizer. *Netherlands Milk and Dairy Journal*, *50*(2), 135-148.

Ding, Q. B., Ainsworth, P., Plunkett, A., Tucker, G., & Marson, H., 2006. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering, 73*, 142- 148.

Garad, S., Wang, J., Joshi, Y., & Panicucci, R. (2010). Preclinical development for suspensions. In A.K. Kulshreshtha, O.N. Singh, G.M. Wall, *Pharmaceutical suspensions: From formulation development to manufacturing* (pp 127- 177). New York, NY: AAPS Press.

Gibson, L. J., & Ashby, M. F. (1997). *Cellular solids: Structure and properties*. Cambridge, Cambridge University Press.

Guy, R. (2001). Introduction. In R. Guy, *Extrusion Cooking: Technologies and Applications* (pp. 1-2). Cambridge: Woodhead Publishing Limited & CRC Press LLC.

Hardham, J. F., Imison, B. W., & French, H. M. (2000). Effect of homogenisation and microfluidisation on the extent of fat separation during storage of UHT milk. *Australian Journal of Dairy Technology*, *55* (1), 16-22.

Hsieh, F., Mulvaney, S. J., Huff, H. E., Lue, S., & Brent, J. (1989). Effect of dietary

fiber and screw speed on some extrusion processing and product variables. *Lebensmittel Wissenschaft Technologie*, *22*(4), 204-207.

Huang, C. C., Chen, Y. F., & Wang, C. C. R. (2010). Effects of micronization on the physico-chemical properties of peels of three root and tuber crops. *Journal of the Science of Food and Agriculture, 90*(5), 759–763.

Jaime, L., Mollá, E., Fernández, A., Martin- Cabrejas, M. A., López- Andréu, F. J., & Esteban, R. M. (2002). Structural carbohydrate differences and potential source of dietary fiber of onion (*Allium cepa* L.) tissues. *Journal of Agricultural and Food Chemistry*, *50*(1), 122- 128.

Jin, Z., Hsieh, F., & Huff, H. E. (1995). Effects of soy fiber, salt, sugar and screw speed on physical properties and microstructure of corn meal extrudates. *Journal of Cereal Science*, *22*(2), 185-194.

Kazamzadeh, M. (2012). Introduction to extrusion technology. In: A. Altan., & M, Maskan, *Advances in food extrusion technology* (pp1-23). Boca Raton, FL: CRC Press.

Kemp, S. E., Hollowood, T., & Hort, J. (2009*). Sensory evaluation a practical handbook.* (pp 849- 850). Oxford, UK: Wiley– Blackwell.

Laufenberg, G., Kunz, B., & Nystroem, M. (2003). Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations. *Bioresource Technology*, *87*(2), 167- 198.

Lagoueyte, N. & Paquin, P. (1998). Effects of microfluidization on the functional properties of xanthan gum. *Food Hydrocolloids, 12*(3), 365–371.

Lin, S. (1967). Porosity and pore- size distribution of soil aggregates. MS Thesis, University of Minnesota, United States.

Liu, W., Liu, J. H., Liu C. M., Zhong, Y. Z., Liu, W. L., & Wan, J. (2009). Activation and conformational changes of mushroom polyphenoloxidase by high pressure microfluidization treatment. *Innovative Food Science and Emerging Technologies*, *10*(2), 142- 147.

McCrae, C. H. (1994). Homogenization of milk emulsions – use of microfluidizer. *International Journal of the Society of Dairy Technology*, *47*(1), 28–31.

Mert, B. (2012). Using high pressure microfluidization to improve physical properties and lycopene content of ketchup type products. *Journal of Food Engineering*, *109*(3), 579-587.

Moscicki, L. & Zuilichem, D. J. V. (2011). Extrusion-Cooking and Related Technique. In L. Moscicki, *Extrusion-Cooking Techniques: Applications, Theory and Sustainability (*pp.1-24). Weinheim: Wiley- VCH, Verlag & Co, KgaA.

Ng, A., Parker, M. L., Parr, A. J., Saunders, P. K., Smith, A. C., & Waldron, K. W. (2000). Physicochemical characteristic of onion (*Allium cepa* L.) tissues. *Journal of Agricultural and Food Chemistry*, *48*(11), 5612–5617.

Oberdörster, G., Oberdörster, E., & Oberdörster, J. (2005). Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. *Environmental Health Perspective, 113*(7), 823- 839.

Olson, D. W., White, C. H., & Watson, C. E. (2003). Properties of frozen dairy desserts processed by microfluidization of their mixes. *Journal of Dairy Science, 86*(4), 1157-1162.

Öztürk, O. K. (2014). Production and characterization of microparticulated corn zein, and its applications on emulsions and bread making. MS Thesis, METU, Ankara.

Paquin, P. & Giasson, J. (1989). Microfluidization as a homogenization process for cream liqueur. Lait *69*, 491–498.

Pai, D. A., Blake, O. A., Hamaker, B. R., & Campanella, O. H. (2009). Importance of extensional rheological properties on fiber-enriched corn extrudates. *Journal of Cereal Science*, 50(2), 227-234.

Prasopsunwattana, N., Omary, M. B., Arndt, E. A., Cooke, P. H., Flores, R. A., Yokoyama, W., Toma, A., Chongcham, S., & Lee, P. S. (2009). Particle size effects on the quality of flour tortillas enriched with whole grain waxy barley. *Cereal chemistry*, *86*(4), 439- 451.

Rehman, Z., Islam, M., & Shah, W. H. (2003). Effect of microwave and conventional cooking on insoluble dietary fibre components of vegetables. *Food Chemistry*, *80*(2), 237- 240.

Riaz, M. N. (2000). Introduction to Extruders and Their Principles. In: M. N. Riaz., *Extruders in Food Applications.* (pp. 1-20). USA: CRC Press.

Riaz, M. N. (2001). Selecting the right extruder. In: R. Guy, *Extrusion Cooking: Technologies and Applications* (pp. 29-48). Cambridge: Woodhead Publishing Limited &CRC Press LLC.

Sahin, S., & Sumnu, G. (2006). *Physical properties of food*s (pp.92). New York: Springer Press.

Sanguansri, P., & Augustin, M.A. (2006). Nanoscale materials development- a food industry perspective. *Trends in Food Science & Technology, 17*(10), 547- 556.

Sawant, A. A., Thakor, N. J., Swami S. B., & Divate, A. D. (2013). Physical and sensory characteristics of Ready-To-Eat food prepared from finger millet based composite mixer by extrusion. *Agric Eng Int: CIGR Journal*, *15*(1), 100-105.

Schieber, A., Stintzing, F.C., & Carle, R. (2001). By- products of plant food processing as a source of functional compounds- recent developments. *Trends in Food Science & Technology, 12* (11), 401-413.

Sriburi, P. & Hill, S. E. (2000). Extrusion of cassava starch with either variations in ascorbic acid concentration or pH. *International Journal of Food Science & Technology, 35* (2), 141- 154.

Stojceska, V., Ainsworth, P., Plunkett, A., İbanoğlu, E., & İbanoğlu, Ş. (2008). Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. *Journal of Food Engineering*, *87*(4), 554- 563.

Tadros, T., Izquierdo, P., Esquena, J., & Solans, C. (2004). Formation and stability of nano-emulsions. *Advances in Colloid and Interface Science,* 303-318.

Tunick, M. H., Van Hekken, D. L., Cooke, P. H., Smith, P. W., & Malin, E. L. (2000). Effect of high pressure microfluidization on microstructure of mozzarella cheese. Lebensmittel-Wissenschaft und-Technologie: *Food Science and Technology*, *33*(8), 538-544.

US Department of Agriculture (USDA), US Department of health and human services. Dietary Guidelines for Americans. Washington, DC: USDA; 2005.

Wan, J., Liu, C. M., Liu, W., Xiong H. W, & Tu, Z. C. (2009). Effects of instantaneous high pressure (IHP) on rheological properties of okara dietary fiber suspension. *Journal of Food Science and Technology- Mysore*, 573- 576.

Wang, S. M., Casulli, J., & Bouvier, J. M. (1993). Effect of dough ingredients on apparent viscosity and properties of extrudates in twin-screw extrusion-cooking. *International Journal of Food Science and Technology*, *28*(5), 465- 479.

Wang, T., Sun, X., Zhou, Z., & Chen, G. (2012). Effects of microfluidization process on physicochemical properties of wheat bran. *Food Research International 48*(2), 742–747.

Wang, T., Sun, X., Raddatz, J., & Chen, G. (2013). Effects of microfluidization on microstructure and physicochemical properties of corn bran. *Journal of Cereal Science, 58*(2), 355–361.

Waldron, K. (2001). Useful ingredients from onion waste. *Food Science and Technology*, *15*(2), 38-41.

Yanniotis, S., Petraki, A., & Soumpasi, E. (2007). Effect of pectin and wheat fibers on quality attributes of extruded cornstarch. *Journal of Food Engineering*, *80*(2), 594-599.

Yıldız, E. (2014). Production of hazelnut skin micro and nano fibers utilization in biscuits. MS Thesis, METU, Ankara.

Zhang, D. & Moore, W. R. (1997). Effect of wheat bran particle size on dough rheological properties. *Journal of the Science of Food and Agriculture*, *74*(4), 490-496.

Zhang, X. C., Tu, Z. C., Zheng, W. W., Li, P., Chen, G., Wang, H., & Dou, Y. X. (2009). Mechanochemical effect on arachin by high pressure microfluidization. *Acta Chemica Sinica,* 2862- 2866.

Zhu, L. J., Shukri, R., Mesa-Stonestreet, N. J. D., Alavi, S., Dogan, H., & Shi, Y-C. (2010). Mechanical and microstructural properties of soy protein - high amylose cornstarch extrudates in relation to physiochemical changes of starch during extrusion. *Journal of Food Engineering*, *100*(2), 232-238.

APPENDIX A

IMAGES OF THE PROBES

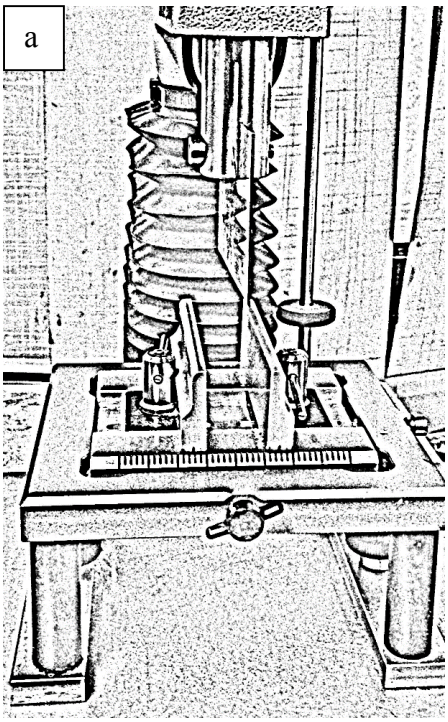

Figure 18 Image of the sharp blade probe used

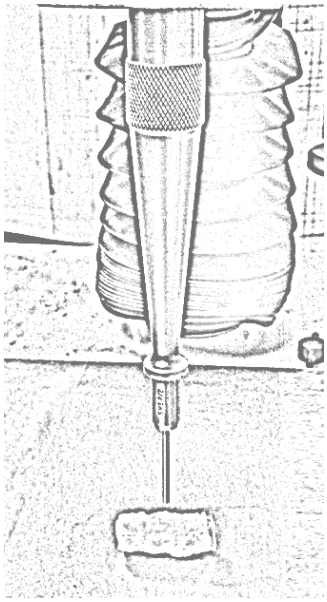

Figure 19 Image of the puncture probe

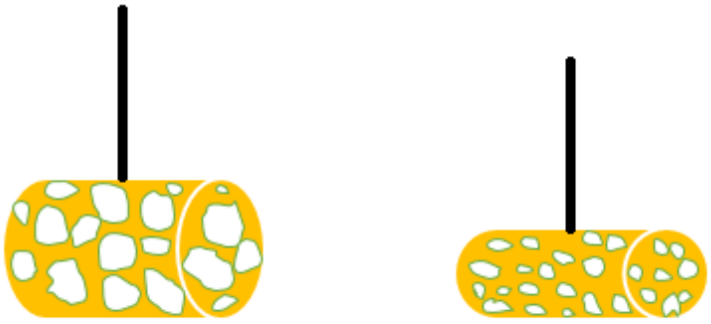

Figure 20 Images of puncture probe with the extruded products which have different diameters.

APPENDIX B

IMAGES OF EXTRUDATES

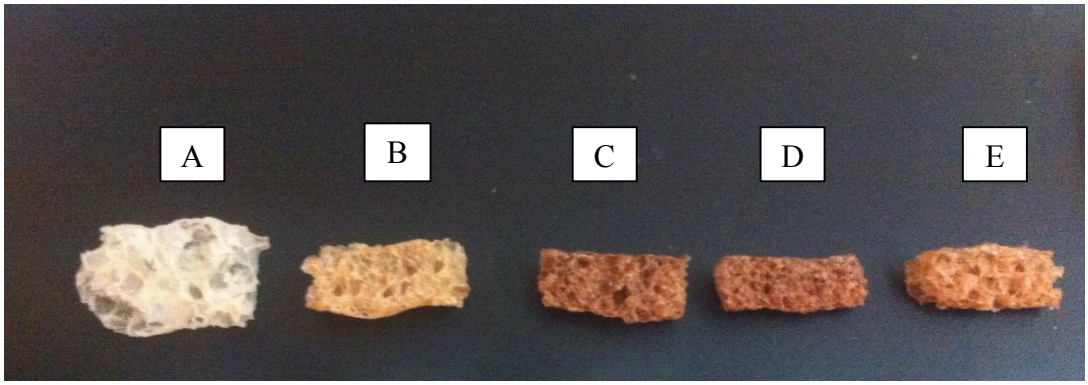

Figure 21 Pictures of half of the extruded products A) Control sample B) 2% microfluidized onion skin added sample C) 6% microfluidized onion skin added sample D) 10% microfluidized onion skin added sample E) 6% non-microfluidized onion skin added sample

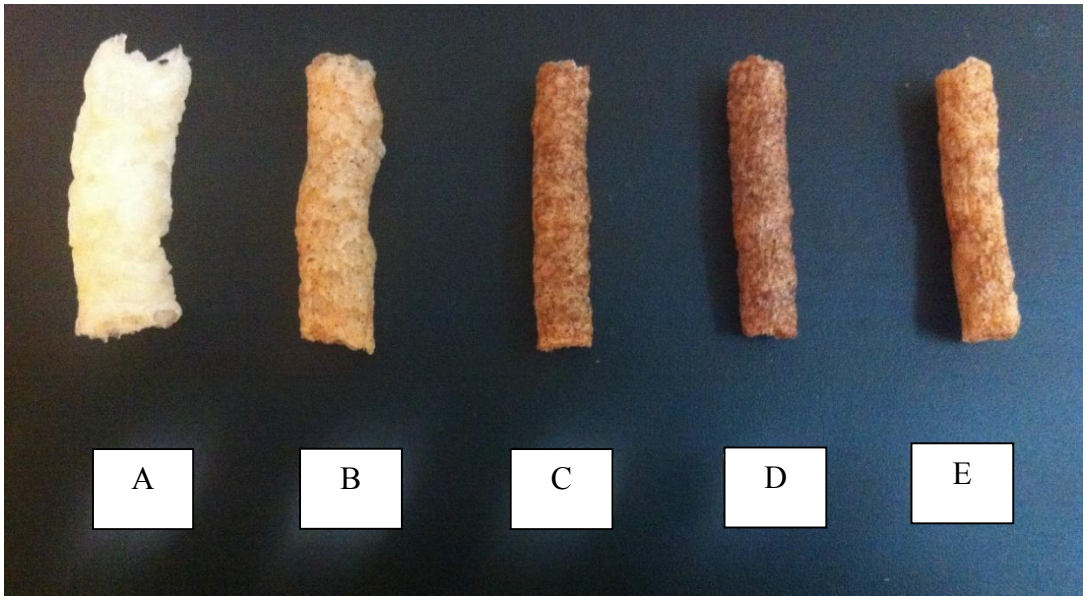

Figure 22 Pictures of the whole extruded products top view A) Control sample B) 2% microfluidized onion skin added sample C) 6% microfluidized onion skin added sample D) 10% microfluidized onion skin added sample E) 6% non-microfluidized onion skin added sample

Figure 23 Pictures of the whole extruded products side view A) Control sample B) 2% microfluidized onion skin added sample C) 6% microfluidized onion skin added sample D) 10% microfluidized onion skin added sample E) 6% non-microfluidized onion skin added sample.

APPENDIX C

IMAGES OF PUNCTURE TESTS

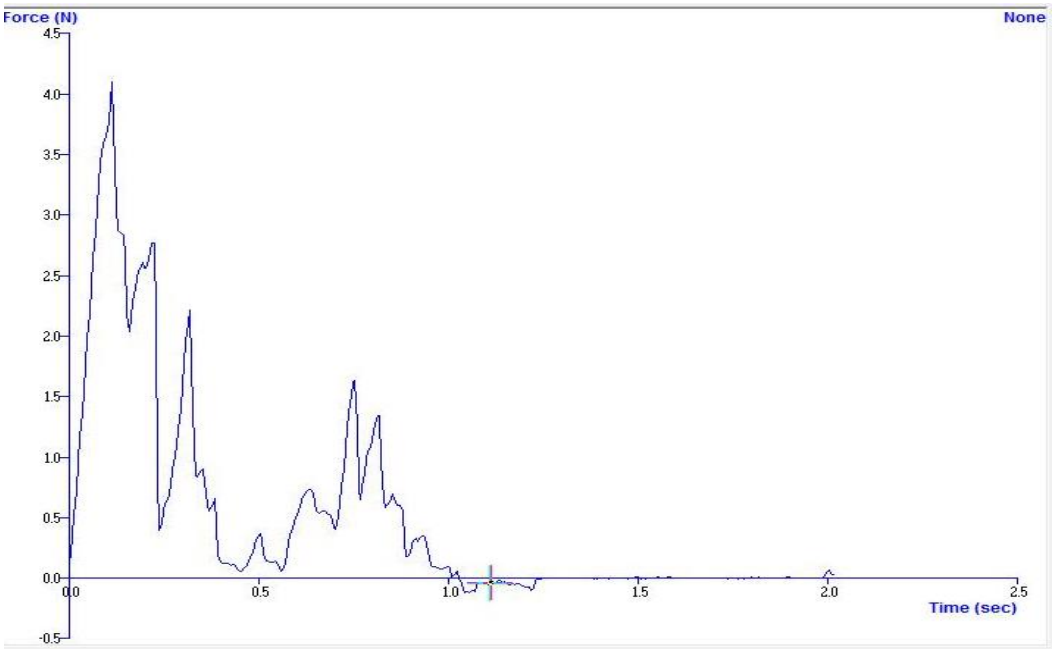

Figure 24 Sample force time curve of a control sample

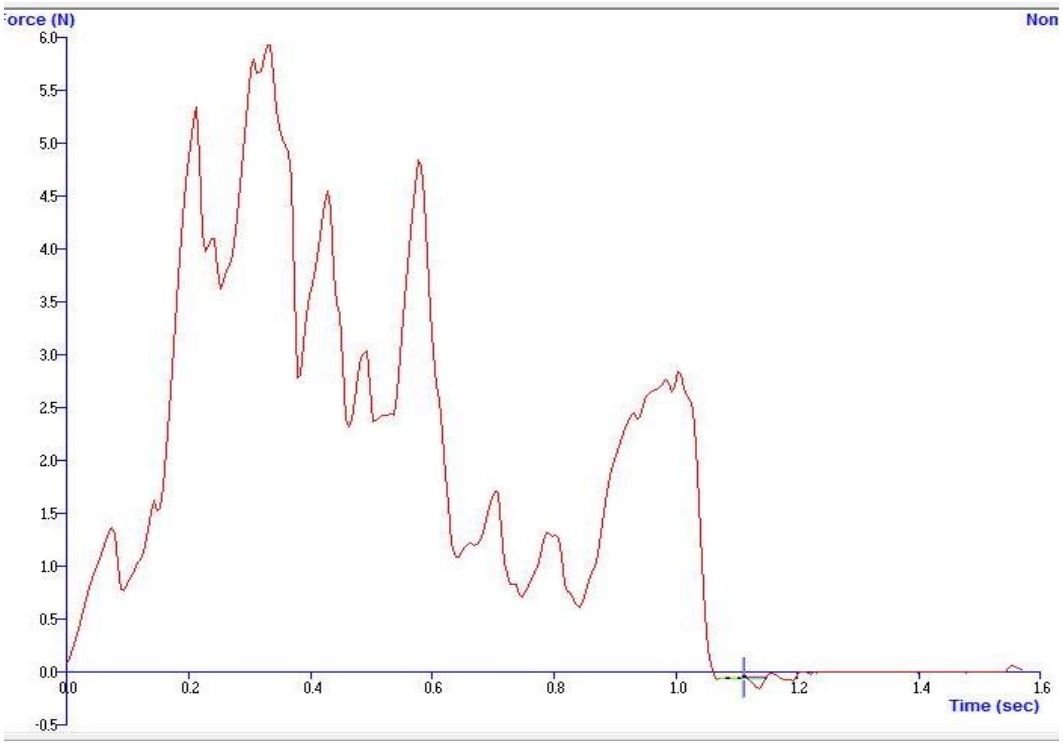

Figure 25 Sample force time curve of 2% microfluidized onion skin added sample

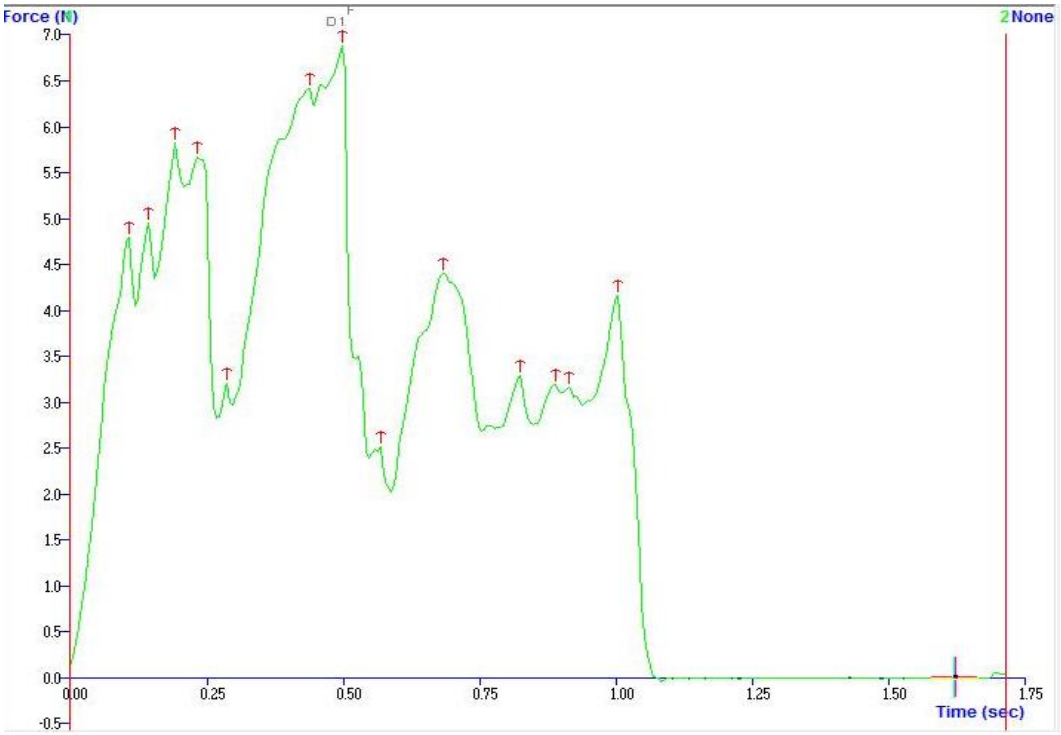

Figure 26 Sample force time curve of 6%mf onion skin added sample

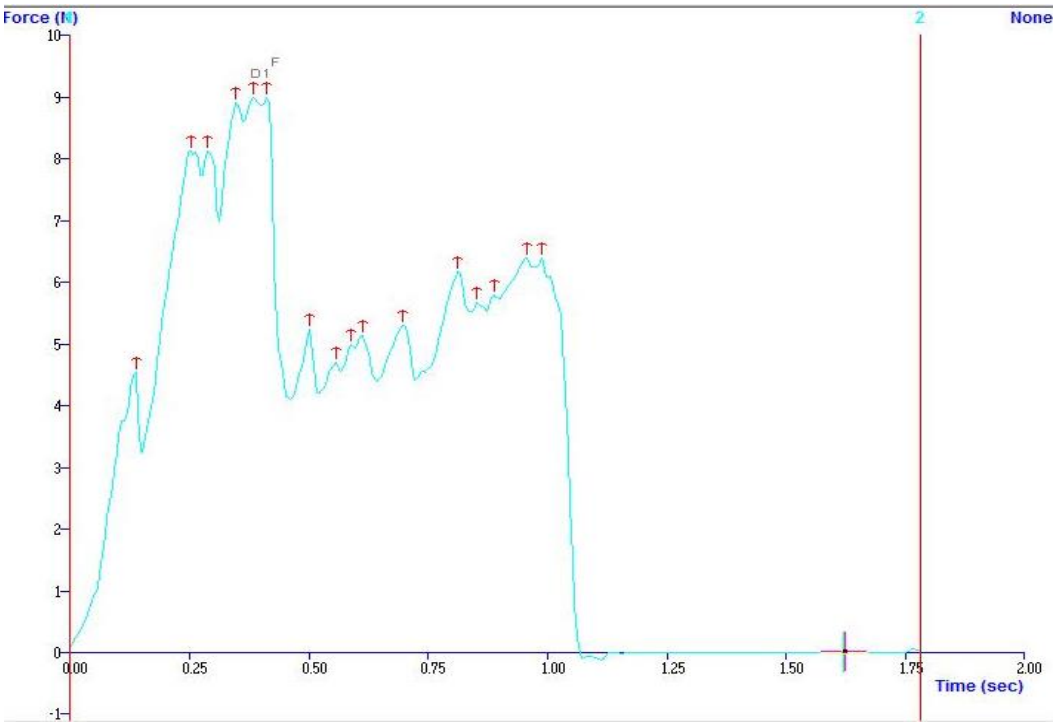

Figure 27 Sample force time curve of 10 % mf onion skin added sample

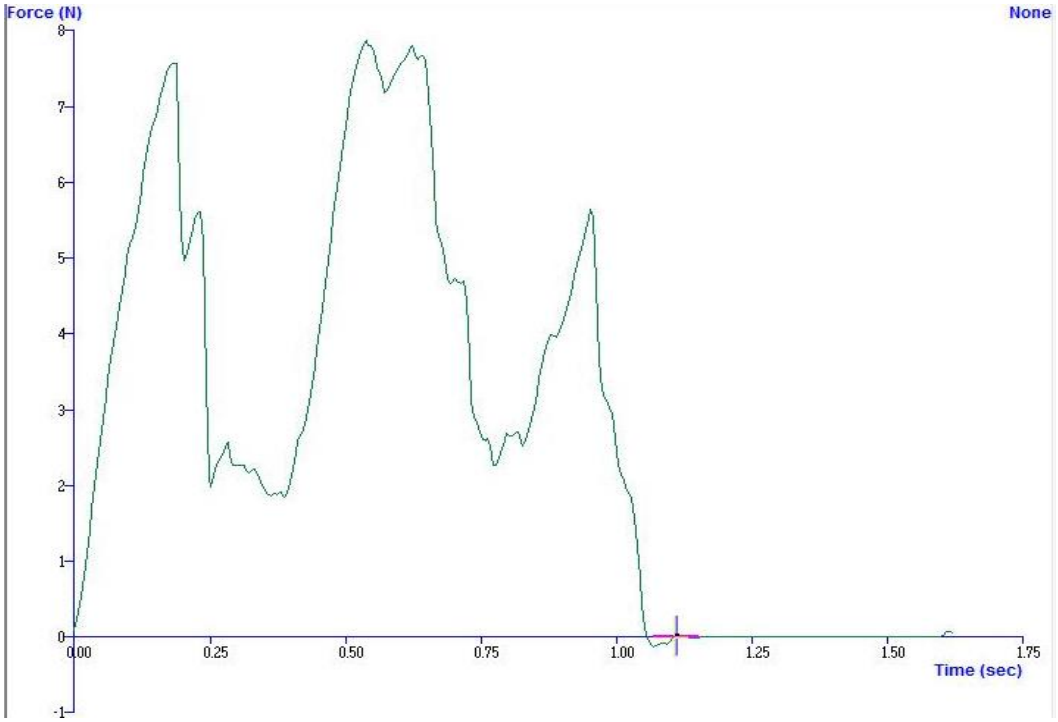

Figure 28 Sample force time curve of 6%not mf onion skin added sample