EFFECT OF TOMATO, RED PEPPER AND CARROT PULP ADDITION ON THE QUALITY OF EXTRUDATES

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ABSTRACT

EFFECT OF TOMATO, RED PEPPER AND CARROT PULP ADDITION ON THE QUALITY OF EXTRUDATES

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Effects of tomato pulp, red pepper pulp and carrot pulp addition on the quality parameters of the corn grit extrudates were investigated. Addition of tomato pulp had no statistically significant effect on longitudinal expansion index, volume expansion index, bulk density and porosity values of the extrudates, however, a decrease was observed in sectional expansion index with the addition of tomato pulp. Sectional expansion index indicated no statistically significant difference with the addition of red pepper pulp. Longitudinal expansion index, volume expansion index and porosity values were decreased, whereas bulk density of the extrudates were increased as a result of red pepper pulp addition. Addition of carrot pulp had no statistically significant effect on sectional expansion index, longitudinal expansion index, volume expansion index, porosity and bulk density of the extrudates. For all the pulp added extrudates lightness was decreased, while redness and yellowness were increased when compared to no pulp added extrudates. No statistically significant difference was observed in water absorption index, water solubility index, hardness and fracturability values of the extrudates with pulp addition. Sensory values were also not indicated a difference with the addition of pulp, when the preferences of the panelists were considered. The results suggest that tomato pulp, red pepper pulp and carrot pulp can successfully be added as a functional ingredient to develop new functional extruded food products.

Keywords: Extrusion, quality parameters, tomato, red pepper, carrot

ÖZ

DOMATES, KIRMIZI BİBER VE HAVUÇ POSASI EKLEMENİN EKSTRUDE ÜRÜN KALİTESİ ÜZERİNE ETKİLERİ

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Fonksiyonel katkı maddesi olarak domates, kırmızı biber ve havuç posası eklemenin ekstrüde ürün kalitesi üzerindeki etkileri araştırılmıştır. Domates posası eklemek ekstrüde ürünlerin enine genleşme indeksinde azalmaya sebep olurken, boyuna genleşme indeksinde, hacim genleşme indeksinde, yığın yoğunluğunda ve gözeneklilik değerlerinde istatistiksel olarak anlamlı bir değişiklik yaratmamıştır. Kırmızı biber posası eklemek, ekstrüde ürünün enine genleşme indeksinde istatistiksel olarak anlamlı bir fark yaratmamıştır. Kırmızı biber posası eklenince boyuna genleşme indeksi, hacim genleşme indeksi ve gözeneklilik değerleri azalırken, yığın yoğunluğunda artış gözlemlenmiştir. Havuç posası eklemek ekstrüde ürünün enine genleşme indeksi, boyuna genleşme indeksi, hacim genleşme indeksi, gözeneklilik ve yığın yoğunluğu değerlerinde istatistiksel olarak anlamlı bir değişime neden olmamıştır. Posa eklemek ekstrüde ürünün açıklık değerinde azalmaya, kırmızılık ve sarılık değerlerinde artışa neden olmuştur. Su emme indeksi, suda çözünebilirlik indeksi, sertlik ve gevreklik değerleri posa eklenmesi durumunda farklılık göstermemiştir. Duyusal analiz sonuçlarında da posa eklemek istatistiksel olarak anlamlı bir fark yaratmamıştır. Sonuçlara göre fonksiyonel katkı maddesi olarak domates, kırmızı biber ve havuç posası ekleyerek fonksiyonel özelliklere sahip yeni ekstrüde ürünler üretilebilir.

Keywords: Ekstrüzyon, kalite parametreleri, domates, kırmızı biber, havuç

To my beloved family

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$\Delta V_{(cylinder)}$	: Volume displacement of the fluid in the cylinder (cm^3)
$\rho_{(extrudate)}$	: Bulk density of the extrudate (g/cm^3)
$\rho_{(paraffin)}$	: Density of the paraffin wax (g/cm^3)
$\rho_{(true)}$	: True density (particle density) of the extrudates (g/cm^3)
a*	: Redness- greennes values
A	: Ash weight from residue 1 (g)
b*	: Yellowness- blueness values
B	: Blank content
BA	: Ash weight from blank residue 1 (g)
BP	: Protein weight from blank residue 2 (g)
BR_1	: Residue weight of blank 1 (g)
BR_2	: Residue weight of blank 2 (g)
D_e	: Diameter of the extrudate (mm)
D_d	: Diameter of the die (mm)
L*	: Lightness values
LEI	: Longitudinal Expansion Index
$m_{(dissolved)}$	: Dry weight of dissolved solids in supernatant (g)
$m_{(dry)}$	: Dry weight of original solid sample (g)
$m_{(extrudate)}$	: Weight of the extruded sample (g)
$m_{(paraffin)}$	: Weight of the paraffin, used to cover the extruded sample (g)
$m_{(sediment)}$	: Weight of sediment after removal of the supernatant (g)
$m_{(total)}$	: Weight of the paraffin covered extruded sample (g)

m_1	: Weight of sample 1 (g)
m_2	: Weight of sample 2 (g)
P	: Protein weight from R_2 (g)
P_i	: Initial pressure at the first channel (atm)
P_f	: Final pressure of the system after the valve was opened (atm)
R_1	: Residue weight 1 from m_1 (g)
R_2	: Residue weight 2 from m_2 (g)
SEI	: Sectional Expansion Index
SEM	: Scanning Electron Microscope
VEI	: Volume Expansion Index
$V_{(extrudate)}$	: Bulk volume of the extrudate (cm^3)
$V_{(marble)}$	: Volume of the marble (cm^3)
$V_{(paraffin)}$	: Volume of the paraffin, used to cover the extruded sample (cm^3)
$V_{(true)}$	: True volume of the extrudates (cm^3)
V_1	: Volume of the first chamber (cm^3)
V_2	: Volume of the gas reservoir (cm^3)
WAI	: Water Absorption Index
WSI	: Water Solubility Index

CHAPTER 1

INTRODUCTION

1.1 SNACK FOODS

1.1.1 Definition of Snack Foods

‘Snack foods’ are portion of foods, smaller than regular meals, consumed as a light meal between conventional main meals or as a partial replacement for a regular meal (Gatenby, 1997). Providing a brief supply of energy, snack foods suppress the hunger at other times than meals, but the term ‘snack’ also refers to a food to be consumed just for pleasure.

1.1.2 Snack Food Consumption

‘Snacking’ is a world wide used verb now, that describes the act of eating snack foods (Gatenby, 1997). Age, region of residence and socioeconomic statues of people are determinative parameters for the level of snacking (Savige et al., 2007). Snacking level of younger children is higher when compared with the older ones’, and the families with higher income and education levels consume more snacks (Jahns et al., 2001). Snacking behaviour in urban residents is more common when compared to the ones who live in rural residents (Savige et al., 2007). During the past few decades, prevalence of snacking has significantly increased, regardless of the region of residence or age group, and snacks have become very important part of markets (Jahns et al., 2001; Sebastian et al., 2008; Piernas and Popkin, 2009).

1.1.2.1 Snack Food Consumption of Children and Adolescents

Jahns et al. (2001) reported that the prevalence of snack food consumption among U.S children increased from 77% to 91%, between the years 1977 and 1996. As the energy contribution of the snacks was one fifth of daily calorie intake in the year 1977, with an increase of 30%, it reached to one fourth in 1996. As well as children, snacks also became the considerable part of total dietary intake of the adolescents (Sebastian et al., 2008). American youths are leading the world with snack consumption, as 87-88% of them consume at least one snack for a day. 25% of their total daily calorie intake is from snacks (Savige et al., 2007).

Snack consumption is not only common in America but also in all around the world. Based on the survey in 1987, Anderson et al. (1993) reported that fifteen year old Scottish adolescents consume 2.8 snacks per day, out of 5.5 eating occasions. Adair and Popkin (2005) declared that the extend of snack consumption is 86%, 70.7% and 11.8% among Phillippino youth (Cebu), Russian youth and Chinese youth, respectively. 18%, 16% and 1% of the total daily calorie intake was reported to be from snacks, for Phillippino youth, Russian youth and Chinese youth, respectively, based on the survey conducted in the year 2003 (Adair and Popkin, 2005). From the recent surveys, Savige et al. (2007) have reported that 91% of the children were snacking at least once a day and the major part of the children’s daily calorie intake is from snacks (Branscum and Sharma, 2011).

1.1.2.2 Snack Food Consumption of Adults

Piernas and Popkin (2009) have reported about the snack food consumption among adults. According to the study, over the past two decades, prevalence of snackers among U.S adults and contribution of the snacks to their daily calorie intake have steadily increased, as well as the children and adolescents. Based on the survey in the years 2003-2006, 97% of the adults in U.S (≥19 years) were reported to consume snacks over 2 day period, whereas it was used to be 71% in 1977. The energy contribution of the snack to the daily calorie of U.S adults also increased and reached to 24% (Piernas and Popkin, 2009).

1.1.2.3 Snack Food Consumption in Turkey

The situation is not different in Turkey. Akman et al. (2010) have reported that regular meal consumption is low among the Turkish adolescents. 61% of the Turkish adolescents are skipping regular meals and consume snacks instead.

1.1.3 Health Aspects of Snack Food Consumption

Eating habits have changed all around the world for the past few decades and this can be summarised as decreasing the consumption of regular meal and increasing the snack food consumption.

Snacks are relatively cheap and easy to access products, both at home and outside. In such a busy world, having not much time to eat a regular meal and to be constrained to eat away from home, people have been forced to choose easy to access snacks instead of qualified meals (Moshfegh and Goldman, 2006; Branscum and Sharma, 2011). Therefore, snacks became very important part of the diet and contribute very much to the consumers' daily nutrient and calorie intake. However, snack foods are energy dense but nutrient poor products which are considered as junk foods (Gatenby, 1997). Overconsumption of such nutrient poor products instead of regular meals may cause several problems such as overweight and obesity.

The prevalence of obesity among children and adolesents was 1.6% for Africa (1987-2003), 27.7% for America (1988-2002), 23.5% for Eastern Mediterenian (1992-2001), 25.5% for Europe (1992-2003), 10.6% for South East Asia (1997-2002), 12% for West Pacific and it was expected to reach to the values of 46.4% for America, 41.7% for Eastern Mediteranian, 38.2% for Europe, 22.9% for South East Asia and 27.2% for West Pacific, by the year 2010 (Kosti and Panagiotakos, 2006). Branscum and Sharma (2011) reported that the prevalence of overweight and obesity was 31.9% for U.S children and adolescent. It is obvious that there is a relation between snacking and obesity. So, less energy dense, healthy and appealing snacks needed to be produced.

1.2 FUNCTIONAL FOODS

With the development of technology and food science, health consciousness of people rises day by day. In recent years, improved knowledge and health consciousness, together, make customers not only seek for nutritious products but also search for functional components which are known as health promoting foods. This makes the health promoting foods to be more popular and now, there is a growing realization of the market potential for functional foods, based on the principle of added value linked to health benefit. So, continuous improvement is essential for the industry.

1.2.1 Definition of Functional Foods

There is a large number of definitions of functional foods but there is also a great variations within these definitions. So, no simple, universally accepted definition of functional foods is available (Doyon and Labrecque, 2008). Within an article named "Functional foods: a conceptual definition", Doyon and Labrecque (2008) stated that there are 26 definitions. They analyzed those definitions if they meet the criteria that should be involved in the definition of the functional foods. Criteria were nature, function, regular consumption and health benefit information in the definitions. Only four of these definitions meet all criteria.

"A functional food is a conventional food or a food similar in appearance to a conventional food, it is part of a regular diet and has proven health-related benefits and/or reduces the risk of specific chronic disease above its basic nutritional functions" according to the definition of Health Canada (2006) which is the latest definition of functional foods that meet all four criteria stated in the article of Doyon and Labrecque (2008). On the other hand, "Foods or food components that provide a health benefit beyond basic nutrition" is the definition of The Institute of Food Technologists.

1.2.2 Why do we need Functional Foods?

Human cells are continuously subjected to the oxidizing agents. Large biomolecules, such as proteins, DNA and lipids can be damaged as a result of oxidative stress which is a result of ineffectiveness of a body to maintain the balance between oxidants and antioxidants. This may result in an increasing risk of chronic diseases, including cancer and cardiovascular disease (Liu, 2003). Supplying resonable amounts of antioxidant to the foods, addition of functional ingredients may be the solution to maintain the balance among them and decrease the risk of such diseases.

1.2.3 Tomatoes as a Functional Ingredients

Tomatoes (*Solanum lycopersicum L.*) are edible red fruits which are accessible all year round with reasonable prices. They are leading all the fruit and vegetables with highest consumption rate. Consumption of tomato and tomato products is being considered as a nutritional indicator of good dietary habits and healthy life styles, as they are rich in health related food components (George et al., 2004).

Dietary fiber is one of the most nutritionally important constituent of the tomatoes. Dehgha-Shoar et al. (2010) stated that more than 70% (w/w, db) of the tomato skin and 15% (w/w, db) of the tomato paste consists of dietary fiber. Laxation and modulation of blood glucose are beneficial physiological effects attributed to the consumption of dietary fiber.

On the other hand, tomatoes are reservoir of various antioxidants such as ascorbic acid, vitamin A, carotenoids, flavonoids and phenolic acids (George et al., 2004). Antioxidants are playing an important role in reducing risk of chronic diseases since they are capable of inhibiting or retarding the biomolecular oxidations (Borguini and Torres, 2009). Among these, lycopene which is the carotenoid responsible for the vibrant red color of the tomatoes, has received the greatest interest due to its high biological activity in the body as an antioxidant (Borguini and Torres, 2009). As they are rich in health related food component and have an important role in decreasing the risk of chronic diseases, tomatoes can be reasonable functional ingredient.

1.2.4 Red Peppers as Functional Ingredients

Red bell peppers are fruits (*Capsicum annuum L.*) which belong to the genus *Capsicum* of the family *Solanaceae*. They are beloved fruits with characteristic color, tangy taste and crunchy texture (Minguez-Mosquera et al., 2008). Red bell peppers contains various carotenoids which make the fruit powerful radical scavenger exibiting antioxidant and anticarciogenic activities (Hirayama et al., 1994; Matsufuji et al., 1998). Capsanthin, β-carotene, violaxanthin, cryptoxanthin, capsorubin and cryptocapsin are the major carotenoids found in red bell peppers comprising 35%, 10%, 10%, 6%, 6% and 4% of the total carotenoids, respectively (Curl, 1962). They are also good sources of vitamin C, vitamin E, provitamin A and present flavonoids as well as phenolic compounds (Palevitch and Craker, 1995; Materska and Perucka, 2005). Red bell pepper can be reasonable functional ingredients due to the presence of antioxidants and their roles in preventing and reducing chronic and age related diseases.

1.2.5 Carrots as Functional Ingredients

Carrots (*Daucus carota sativus*) are important root vegetables which belong to the family of Apiaceae. Due to their high yield potential and easy to use both as fresh and processed, they are cultivated worldwide (Stein and Nothnagel, 1995). The orange colored carrots are more common but yellow, purple, red and white colored carrots are cultivated as well.

The color of typical orange carrot is due to its rich carotenoid content which are predominantly α- and β- carotene (Simon et al., 2008). Carrots contain ɣ- carotene, ζ-carotene, β-zeacarotene and lycopene, as well, even they are in smaller amounts (Simon and Wolff, 1987). Apart from being responsible for the color of a food, carotenoids take over the protective role in human diseases as some of them have provitamin A activity (Simpson, 1983). β- carotene, the most abundant carotenoid in carrot, posseses the maximal provitamin A activity (Simpson, 1983). Within the body, provitamin A may turn into a vitamin A, which is an essential nutrient for the promotion of general growth, embryonic development, immune function, maintenance of visual function and regulation of epithelial differentiation (Tang, 2010; Tanumihardjo, 2011). On the other hand, carrots are also good sources of bioactive compounds like phenolics, polyacetylens and dietary fibers, and rich in minerals like Ca, Fe and Mg (Sharma et al., 2012). Carrots can be resonable functional ingredients, as they contain an appreciable level of variety of different compounds, with significant health promoting properties (Hager and Howard, 2006).

1.3 EXTRUSION TECHNOLOGY

1.3.1 Extrusion

Extrusion is a continuous mixing, kneading, and shaping process through a barrel, in which material is pushed through a die (Akdogan, 1999). This process is used world wide for the production and modification of various products or improvement of the quality of such products (Singh and Smith, 1997).

Extrusion process was first described in a patent by Joseph Bramanh, in the year 1797, about making lead pipe, for which preheated metal was forced through a die with the help of hand driven plunger (Bauser, 2006). Up to the end of nineteenth century, lead was the only extruded material. Alexander Dick, who is known as "father of extrusion", succeeded processing metals, other than lead, with higher melting points (Bauser, 2006). In time, equipment was technologically improved and extrusion technology has been used not only in processing metals but also in many industries, including food industry.

Extruders were first introduced to the food industry in 1870s for the manufacture of sausages and extrusion cooking has been used in the production of pasta for more than seven decades, providing the information that extrusion technology is not new for food industry (Akdoğan, 1999; Karwe, 2008). Today, extrusion has become a promising process due to its advantages over the other cooking technologies (Akdogan, 1999).

1.3.1.1 Extrusion Cooking

Extrusion cooking is a high temperature - short time process where cooking temperature can be as high as 180-190ºC and the residence time is, generally, 20-40s only. With a continuous cooking and shaping process, extruders are designed to give unique physical and chemical functionality to food materials as a result of extrusion process, where is possible to have various end products by changing the ingredients and the processing conditions (Altan et al., 2009).

1.3.1.2 Advantages of Extrusion Cooking

Extrusion is an energy efficient, environmentally friendly and highly productive process with low operating cost which is also easy to implement (Guy, 2001). Due to the high temperature, more hygenic extrudates can be prepared as a result of extrusion process. Undesirable enzymes are denaturated, some anti-nutritional factors are inactivated and the final product is sterilized, while retaining natural colours and flavours of foods during the extrusion process (Singh et al., 2007b). In addition, exposure to high temperatures only for a short time decreases the loss of heat sensitive components (Singh et al., 2007b).

The market expects new food products and to be attractive from an economic point of view (Moscicki and Zuilichem, 2011). Extrusion cooking technology can meet all these expectations by making it possible for producer to have different functionalities in a large variety of products with high quality, due to numerous ingredients and a wide range of processing conditions (Altan et al., 2009).

1.3.1.3 Products of the Extrusion Cooking

Extrusion, today, is being used in the production of various products such as ready to eat breakfast cereals, pastas, snack pellets, baby food, starches, meat analogs and confectionary for human consumption, besides pet foods and animal feed products (Moscicki and Zuilichem, 2011). Extrusion technology has been increasingly used in the production of cereal based snacks which are prefered especially for their pleasing textural mouth feel and good swelling properties, besides their good taste and flavour (Bhattacharyya et al., 2006; Santosa et al., 2008). However, snack foods are considered as junk foods. They have high glycemic index and their nutritional value does not satisfy the needs of health conscious consumers (Atkinson et al., 2008).

As the extrusion devices, extruders, are technologically convenient for the fortification or nutritional enrichment of the carbohydrate based snacks with functional ingredient addition, and as the extrusion enables the development of new products by using various ingredients and a wide range of processing conditions, extrusion became the most commonly used technology for the snack production (Narbutaite et. al., 2008).

1.3.1.4 Food Extruders

Food extruders are the devices used for extrusion cooking which generate the suitable conditions and accelerate the shaping and re-structuring process for food ingredients (Riaz, 2000). There are two types of classification for extruders. One is based on the source of heat and level of moisture in the material during extrusion. These are dry extruders and wet extruders. However, the second type of classification is more common and based on screw designs. These extruders are single screw extruders and twin screw extruders (Riaz and Rokey, 2012).

1.3.1.4.1 Single Screw Extruders

Single screw extruders are relatively simple extruders when compared with twin screw extruders and has one shaft in the barrel (Moscicki and Zuilichem, 2011; Riaz and Rokey, 2012). Extruder barrel, screw, preconditioning cylinder, die and knife are the components of a typical single screw extruder (Riaz and Rokey, 2012). The mission of the screw of this type extruder is to convey, compress, melt and plasticize the food material and to force it through the die at the end of the barrel, under pressure (Moscicki and Zuilichem, 2011).

Single screw extruders rely on drag flow; the couette flow between the rotating screw and the stationary barrel (Birley et al., 1992; Moscicki and Zuilichem, 2011). On the other hand, at the end of the extruder, at the die, there is a flow restriction that creates a pressure gradient along the screw and results with a back flow naming pressure flow. This pressure flow is the poiseulle flow supressing the flow through the extruder (Birley et al., 1992).

Single screw extruders are suitable for the raw materials with high friction coefficient and used in the production of direct expanded corn snacks, texturized vegetable protein, ready to eat breakfast cereal, full fat soy and pet food (Riaz and Rokey, 2012).

The main disadvantage of the single screw extruders is the poor mixing, so raw materials must be properly prepared before feeding the extruder (Moscicki and Zuilichem, 2011). The size of the die is determinative on the pressure flow (back flow). Small die sizes causes higher back flow due to higher resistance and reduces the extruders output. In fact, blokage of these dies results in a sudden increase in pressure causing a powerfull back flow which may even lockout the machine (Moscicki and Zuilichem, 2011).

In summary, single screw extruders rely on drag flow and its draw back is pressure flow. The net flow depends especially on the screw speed and geometry of the screw. It has been used to be utilized in the production of the snacks and breakfast cereals but there is a lot of draw backs of using single screw extruders and the efficiency is limited when compared with twin screw exturders (Moscicki and Zuilichem, 2011). Therefore, in recent years, twin screw extruders has begun to challange the dominance of the single screw extruder for snack production.

1.3.1.4.2 Twin Screw Extruders

When compared to single screw extruders, twin screw extruders are more complex considering their desing and heat exchangers (Figure 1 & 2). This complexity and the cost of aquisition is the only drawback. On the other hand, with this design, they are more universal. Their advantages include high versatility, lower energy consumption and the ability to broaden the production assortment, significantly (Moscicki and Zuilichem, 2011; Riaz and Rokey, 2012). The melting mechanism, mixing and pumping differs in twin screw extruder besides the screw geometry. Screws in twin screw extruders can be co-rotating or counter-rotating.

Figure 1. The laboratory scale twin screw extruder used in the study

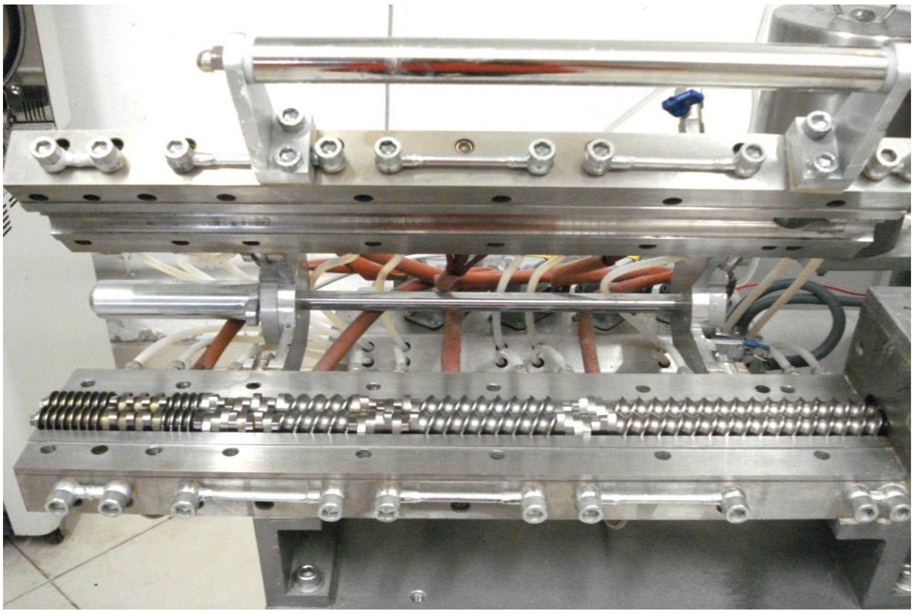

Figure 2. The screws of the twin screw extruder used in the study

1.3.1.4.2.1 Co-Rotating Twin Screw Extruders

When viewed from the same end, the screws of this type extruders rotates in the same direction (Figure 3). Higher productivity and good mixing features make them to be used to a greater extent, besides the advantages of operating at high screw speeds, specifically up to 700 rpm, its pumping efficiency, self cleaning mechanism, uniformity of processing and good control over residence time distribution (Riaz, 2000; Moscicki and Zuilichem, 2011). Good efficiency of the material transportation, mixing, plasticizing and extrusion can be counted as the character of the co-rotating twin extruders (Moscicki and Zuilichem, 2011).

Co-rotating twin extruders also rely on drag flow like single screw extruder. The material is forced to move forward with the help of screws without allowing the material to be locked in the space between the screw and the wall of the barrel (Moscicki and Zuilichem, 2011). When compared with single screw extruders, heat exhangers of the co-rotating twin screw extruders are more complex and co-rotating extruders offer better conveying, allowing them to handle sticky and other difficult to convey food ingredient (Moscicki and Zuilichem, 2011).

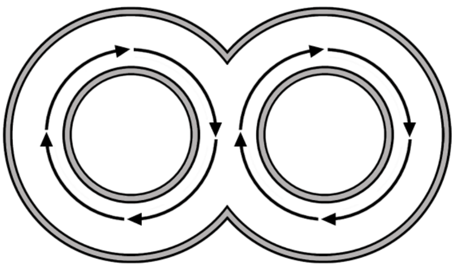

Figure 3. Schematic diagram of the front view of co-rotating twin screw

1.3.1.4.2.2 Counter-Rotating Twin-Screw Extruders

The screw speed of this type extruders is much more slow (up to 150 rpm) when compared to co-rotating twin screw extruders. However, effective mixing of the material is possible (Moscicki and Zuilichem, 2011). They are good in processing relatively nonviscous materials requiring low speeds and long residence times (Riaz, 2000).

They work by generating high pressure in the barrel closed C-shaped chamber on the screw, like a positive-displacement pump and back flow of the material is very small, due to tiny clearance between the screws and the barrel (Moscicki and Zuilichem, 2011). Counter- rotating twin screw extruders are special purpose machinery and using them for the production of simple forms of extrudates would be uneconomic and energy consuming (Moscicki and Zuilichem, 2011).

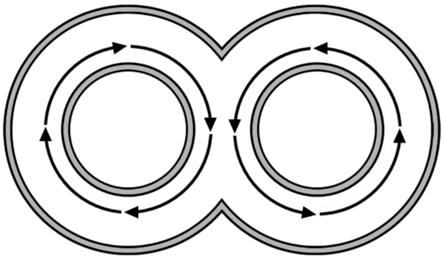

Figure 4. Schematic diagram of the front view of counter-rotating twin screw

1.3.2 Mechanism of Extrudate Expansion

Food extrusion is a continuous cooking and forming process. During the extrusion cooking, moving along the barrel, the food materials are subjected to high temperatures and pressures in combination with shearing stresses (Chen et al., 1991; Seethamraju and Bhattacharya, 1994; Ding et al., 2006; Cheng and Friis, 2010). Moistened, expansive, starchy and/or protenacious food materials undergo physical and chemical changes such as gelatinization and breakdown of starch, denaturation of proteins and formation of complexes between starch, lipids and proteins (Lai and Kokini, 1991; Milan-Carrillo et al., 2002; Singh et al., 2007b). These physical and chemical changes transform the powdery material into viscoelastic melt (Seethamraju and Bhattacharya, 1994; Moraru and Kokini, 2003). Leaving the die, extrusion cooked melt suddenly face with pressure drop that causes a flash off of internal moisture and hence, nucleation of the bubbles in the molten extrudate (Arhaliass et al., 2003; Moraru and Kokini, 2003). Expansion of the bubbles stop when the viscoelastic matrix becomes glassy (Moraru and Kokini, 2003). Porous, sponge like structure is obtained within the extrudate due to the air cells generated.

1.3.3 Factors Affecting the Product Quality

The end product quality of the extrudates depend both on the physico-chemical characteristics of raw materials and on the processing conditions, which can be manupulated by changing operational variables (Bhattacharya et al., 1982; Bhattaccharya, 1997). Since expansion of the extrudates mainly depends on the gelatinization of starch, starch is the main polymeric component of the feed (Moraru and Kokini, 2003). Rice, corn, potato and taro like starchy materials have been popular feed materials due to their expansion characteristics and availability (Bhattacharyya et al., 2006). The other components of the feed material, the ingredients such as salt, sugar etc., the particle size and the moisture content of the feed are also determinative on the expansion of the extrudates since they affect the gelatinization behaviour of the starch (Anderson, 1982; Seethamraju and Bhattacharya, 1994).

Type of the extruder, the screw configuration and the die also affects the end product quality besides the operational variables which are the feed rate, the screw speed and the temperature profile in the barrel sections (Anderson, 1982; Chen et al., 1991; Seethamraju and Bhattacharya, 1994; Ilo and Berghofer, 1999). Modifiying any of these parameters; changing of the raw materials, type of the extruder and the process parameters, it is possible to have extrudates with different physical properties or totally different extrudates.

1.3.4 Quality Parameters

Quality, which indicates the products' degree of excellence, is sum of the factors that affect the acceptibility of a product, in the countries where food is abundant (Potter and Hotchkiss, 1995). Quality is also determinative on the price of a product since people are willing to pay some higher amounts for foods with higher quality (Potter and Hotchkiss, 1995).

1.3.4.1 Expansion Characteristics

Determining the quality of the extruded products, expansion related parameters are playing an important role (Fayose, 2013). Sectional expansion index, longitudinal expansion index, volume expansion index, bulk density and porosity data, all, can be used to figure out the expansion characteristics of the extruded products.

Sectional expansion index (SEI) describes the expansion in the radial direction and longitudinal expansion index (LEI) desribes the expansion in the axial direction. On the other hand, volume expansion index (VEI), bulk density and porosity give information about the expansion in all directions (Alvarez-Martinez et al., 1988; Falcone and Phillips, 1988).

Several researchers suggested that the expansion of the extrudates depends on the degree of starch gelatinization (Chinnaswamy and Hanna, 1988; Case et al., 1992). Starch gelatinization is an irreversible phase transition process of starch that includes distruption of the crystalline structure of a starch under specific water content and temperature conditions; breaking down the hydrogen bonds of starch molecules and allowing the hydrogen bonding sites of water to be linked with hydroxyl groups of amylose and amylopectin (Hoover, 2001; Briffaz et al., 2014). As a result, granule swelling and solubility increases (Hoover, 2001). Modification of the extrusion parameters make significant changes on the gelatinization of starch, thus, expansion characteristics of the extrudates. Ingredients, temperature, screw speed and feed rate are found to be effective on the expansion characteristics of the extrudates (Falcone and Phillips, 1988; Lue et al., 1991; Badrie and Mellowes, 1992; Balandran-Quintana et al., 1998; Ilo et al., 1999; Hashimoto and Grossmann, 2003; Ding et al., 2005; Yanniotis et al., 2007; Singh et al., 2007a; Altan et al., 2008a; Altan et al., 2008b; Duarte et al., 2009).

1.3.4.1.1 Ingredients

Starch is the key component for gelatinization and addition of other components such as proteins, sugars, fats and fiber act as diluents (Moraru and Kokini, 2003). Before expanding to their full potential, fiber causes a premature rupture of the air cells (Lue et al., 1991). Therefore, composition of the feed has significant effect on the expansion characteristics of the extrudates.

Changes in the rheological properties of the melt, specifically elasticity and viscosity of the melt, also affect the expansion characteristics of the extrudates. Launay and Lisch (1983) proposed that elasticity of the melt influences the expansion in radial direction and viscosity of the melt influences the expansion in axial direction.

Increasing fiber content decreases the sectional expansion index (Lue et al., 1991; Badrie and Mellowes, 1992; Ilo et al., 1999; Hashimoto and Grossmann, 2003; Singh et al., 2007a; Yanniotis et al., 2007; Altan et al., 2008a; Altan et al., 2008b; Duarte et al., 2009), longitudinal expansion index (Ilo et al., 1999), volume expasion index and porosity (Yanniotis et al., 2007), whereas increases the bulk density (Badrie and Mellowes, 1992; Liu et al., 2000; Ding et al., 2005; Altan et al., 2008b) since there is an inverse relation between bulk density and overall expansion (Ilo et al., 1999). However, Lue et al. (1991) had reported reduced radial expansion and more elongation of the corn extrudates as a result of the increase in sugar beet fiber (0-30%).

In several studies, increasing moisture content decreased the sectional expansion index (Falcone and Phillips, 1988; Ilo et al., 1999; Hashimoto and Grossmann, 2003; Singh et al., 2007a), longitudinal expansion index (Ilo et al., 1999), volume expansion index and porosity, whereas increases bulk density which is inversely related with overall expansion (Ilo et al., 1999 ; Ding et al., 2005). However, in the study of Balandran-Quintana et al. (1998), increase in the feed moisture (18-20%) resulted with an increase in the expansion ratio and a decrease in bulk density of the extrudates and this was related with the reduction in viscosity. Liu et al. (2000) also reported an increase in the expansion ratio with increasing the moisture content of the 100% oat flour (18, 19.5 and 21%).

1.3.4.1.2 Temperature

Temperature significantly affects the rheological properties of the melt, thus, expansion characteristics of the extrudates. Increasing barrel temperature resulted in an increase in sectional expansion index and a decrease in bulk density of the extrudates when temperature was 140ºC, 160ºC and 180ºC (Balandran-Quintana, 1998). However, a decrease in sectional expansion index of the extrudates was reported by Falcone and Phillips (1988) where temperatures were 175ºC, 190ºC and 205ºC, by Hashimoto and Grossmann (2003) where temperatures were between 150ºC and 210ºC, and by Duarte et al. (2009) where temperatures were between 100ºC and 200ºC.

Ilo et al. (1999) also reported a decrease in sectional expansion index (SEI) and an increase in the longitudinal expansion index (LEI) of the maize extrudates with increasing temperature (150-190ºC). This was explained by the fact that increasing temperature decreased the elasticity and viscosity of the melt which was decreased the SEI and favoured LEI, respectively. On the other hand, Ding et al. (2005) reported no significant effect of temperature (100º-140ºC) on the expansion of the extrudates.

1.3.4.1.3 Screw Speed

Screw speed affects the residence time, the time of exposure to high temperature, so affects the gelatinization degree, thus expansion. Fayose (2013) suggested that expansion ratio varies directly with duration of operation. Increasing screw speed decreases the residence time and there might not be enough time to complete gelatinization. Screw speed also affects the rheological properties of the melt, as increasing screw speed may cause the degradation of starch molecules and as a result, elasticity of the melt changes (Ilo et al., 1999).

Increasing screw speed decreases sectional expansion index (Lue et al., 1991; Ilo et al., 1999; Hashimoto and Grossmann, 2003). Lue et al. (1991) and Ilo et al. (1999) reported that increasing screw speed increases longitudinal expansion index. Screw speed was increased from 200 to 300 rpm in the study of Lue et al. (1991); from 58-82 rpm in the study of Ilo et al. (1999) and from 120 to 180 rpm in the study of Hashimoto and Grossmann (2003). No significant influence of screw speed was reported for expansion and bulk density of the barley extrudates at 150-200 rpm (Altan et al., 2008a). Ding et al. (2005) was also reported that no significant effect of screw speed (180-320 rpm) on expansion and only slight impact on the bulk density of the rice extrudates, whereas Ilo et al. (1999) and Liu et al. (2000) reported no significant effect of screw speed on product density.

1.3.4.1.4 Feed Rate

Ilo et al. (1999) and Ding et al. (2005) reported that feed rate has an effect on sectional expansion index and longitudinal expansion index, however, Ding et al. (2005) reported no significant effect of feed rate on the bulk density of the rice extrudates.

1.3.4.2 Water Absorption Index and Water Solubility Index

Water absorption index (WAI) and water solubility index (WSI) are important quality parameters of the extruded products which give information about possible behaviour of the materials, in the case of further processed (Sriburi and Hill, 1999). WAI measures the volume occupied by the granule or starch polymer after swelling in excess water and WSI measures the amount of free polysaccharide or polysaccharide released from the granule on addition of excess water (Sriburi and

Hill, 1999). WAI is used as an index of gelatinization, whereas, WSI is used as an indicator of degradation of molecular components (Anderson et al., 1969; Kirby et al., 1988).

WAI and WSI of the extrudates are highly related with the presence of undamaged polymer chains and availability of the hydrophylic groups which can bind water molecules (Gomez and Aguilera, 1983) and these were effected by physio-chemical changes occured during extrusion such as gelatinization of starch which destroys the light packing of polymers and permit their release (Gomez and Aguilera, 1983). Not surprisingly, extrudate expansion is correlated (positively/negatively) with WAI and WSI of the extrudates (Badrie and Mellowes, 1991). Presence of the hydrophylic groups is the reason of high values of WAI (Gomez and Aguilera, 1983), whereas high values of WSI reflects higher macromolecular degradation of amylose and amylopectin molecules of starch (Anderson et al.,1969).

Feed moisture, temperature and screw speed are some of the extrusion parameters that have a significant effect on WAI and WSI (Gujska and Khan, 1991; Badrie and Mellowes, 1991; Jin et al., 1995; Hashimoto and Grossmann, 2003; Ding et al., 2006; Singh et al., 2007a). Ding et al. (2006) indicated that feed rate has no significant effect and fiber was found to have significant effect on WAI and WSI (Artz et al., 1990; Jin et al., 1995; Hashimoto and Grossmann, 2003; Singh et al., 2007a; Altan et al., 2008a).

1.3.4.2.1 Ingredients

Some of the researchers reported that WAI increases with increasing feed moisture (Gujska and Khan, 1991; Badrie and Mellowes, 1992; Balandran-Quintana et al., 1998; Ding et al., 2005; Singh et al., 2007a), however, Ding et al. (2006) reported a decrese in WAI of the extrudates. Several researchers (Gujska and Khan, 1991;

Badrie and Mellowes, 1992; Singh et al., 2007a) reported that WSI decreased with increasing feed moisture, while Ding et al. (2006) reported an increase in WSI of the extrudates with an increase in feed moisture. This could be due to the study conditions of Ding et al. (2006).

Increasing fiber content decreases WAI of the extrudates (Artz et al., 1990; Singh et al., 2007a; Altan et al., 2008a), whereas there are different results for WSI. Badrie and Mellowes (1992) and Singh et al. (2007a) reported a reduced WSI of the extrudates, while Hashimoto and Grossmann (2003) and Altan et al. (2008a) reported an increase in WSI of the extrudates with increasing fiber content. In the study of Jin et al. (1995), increasing fiber content up to 20% resulted with a decrease in WAI and an increase in WSI, however, an increase was observed in WAI while WSI decreased as a result of further increase in fiber content up to 40%.

1.3.4.2.2 Temperature

Artz et al. (1990) and Singh et al. (2007a) stated that increasing barrel temperature increased WAI of the extrudates, however, many others indicated a decrease in WAI of the extrudates with increasing temperature (Ding et al., 2005; Ding et al., 2006; Hashimoto and Grossmann, 2003; Altan et al., 2008a). Some of the researchers reported an increase in WSI of the extrudates (Ding et al., 2006; Singh et al., 2007a; Gujska and Khan, 1991), whereas Altan et al. (2008a) reported a decrease with increasing temperature. Changes in the physico-chemical characteristic of the extrudates not only affected by temperature but also by the time of exposure to heat. This could explain different results found in the studies.

1.3.4.2.3 Screw Speed

Increasing screw speed decreased WAI of the extrudates (Jin et al., 1995) and increased the WSI of the extrudates (Jin et al., 1995; Altan et al., 2008a). Hashimoto and Grossmann (2003) reported that increasing screw speed from 120 to 150 rpm resulted in a decrease in WAI, whereas with a further increase of screw speed up to 180 rpm caused an increase in WAI of the cassava extrudates. In the study of Badrie and Mellowes (1992), increasing screw speed from 425 to 520 rpm resulted with a decrease in WAI and increase in WSI, however further increase of the screw speed from 520 to 560 rpm resulted in increased WAI and decreased WSI. On the other hand, Ding et al. (2006) reported that screw speed (180–320 rpm) had no significant effect on WAI and WSI of wheat-based expanded snacks.

When the screw speed is low, residence time increases, so there is more time to complete the gelatinization and changes might occur in hemicellulose or cellulose such as limited hydrolysis (Artz et al, 1990). As a result, there would be more undamaged polymer chains and a greater availability of hydrophilic group. When the screw speed is high, residence time decreases, so less starch might be gelatinized, however, increase in screw speed increases shear rate and some more degradation of starch occurs (Artz et al, 1990). It would not be easy to comment on the results of WAI and WSI of extrudates without thinking the synergistic effects of screw speed and temperature. Screw speed has significant effect on residence time which determines the time of exposure to heat for melt.

1.3.4.2.4 Feed rate

Feed rate was observed to have no significant effect on WAI of the extrudates (Ding et al., 2005; Ding et al., 2006) and WSI of the extrudates (Ding et al., 2006), however, Ding et al. (2005) reported a significantly decrease in WSI of the extrudates with increasing feed rate.

1.3.4.3 Color

Color is one of the most important quality parameters of a product that appeal to the eye and stimulate us to buy the product. It is important to report about color of the extruded products since color changes provide information about the extent of browning reactions, degree of cooking and pigment degradation during the extrusion process (Altan et al., 2008a).

Chlorophylls, carotenoids, anthocyanins, flavonoids, tannins and betalains are the chemical compounts responsible for the color of the fruits and vegetables (Potter and Hotchkiss, 1995). In order to analyze color of the extrudates, it is important to know the factors that affect these coumpounds.

Chlorophylls, found in chloroplasts, are oil soluble components responsible for the bright green color of the plants. They are bound to protein molecules in highly organized complexes (Potter and Hotchkiss, 1995). Cooking causes a chemical change of cholorophyll to pheophytin because of the denaturation of the proteins and release of the magnesium bond in the chlorophyll. As a result, an olive green or brown color is obtained (Potter and Hotchkiss, 1995).

Flavonoids are yellow plant pigments and anthocyanins are water soluble pigments, responsible for the red and purple color, which belong to the group of flavonoids. Both are pH sensitive (Potter and Hotchkiss, 1995). Tannins are water soluble, phenolic compounds which are colorless under most circumstances. However, in the case of a contact with metal ions, a chemical reaction takes place forming red, brown, green, gray or black colored complexes (Potter and Hotchkiss, 1995).

Betalains are red, water soluble pigments which are degraded by thermal processing (Potter and Hotchkiss, 1995).

Carotenoids are fat soluble pigments whose color varies from yellow through orange to red. They are fairly resistant to heat (Potter and Hotchkiss, 1995). Carotenoids found in corn are zeaxanthin, cryptoxanthin, β-carotene and lutein (deMan, 1990). Lycopene is the main carotenoid in tomatoes which comprises 90% of the total carotenoids in tomato and responsible for the vibrant red color of the tomatoes (Barrett and Anthon, 2008). It is an acyclic, 40 carbon molecule with alternating single and double bonds (Barrett and Anthon, 2008). Even they are in small amounts, tomato contains β-carotene and lutein, as well (Lin and Chen, 2003; Barrett and Anthon, 2008).

Red bell pepper is a ripened form of *Capsicum* fruit whose unripe fruit is green. Color of the red bell pepper is obtained as a result of ripening, during which cholorophylls in the fruit are partially or totally dissapeared and a massive *de novo* biosynthesis took place (Minquez-Mosquera, 2008). All pepper carotenoids contain 9 conjugated double bonds in the cental polyene, however, they contain different end groups. These end groups are the parts that determine the chromophore properties of each pigment (Minquez-Mosquera, 2008). The carotenoids in pepper can be classified into two group which are red and yellow. Capsanthin, capsanthin-5,6-epoxide and capsorubin are the carotenoids belong to red group, whereas zeaxanthin, violaxanthin, antheraxanthin, β-cryptoxanthin, β-carotene, and cucurbitaxanthin A belong to the yellow group (Minquez-Mosquera, 2008).

β- carotene is the main carotenoid in the orange carrots that comprises 44-79% of the total carotenoids in carrot and accompanied by α- carotene (13-38%). Together, they constitude up to 95% of the total carotenoids in carrot. Even they are in small amounts ɣ-carotene, ζ-carotene, β-zeacarotene and lycopene are also present in minor amounts (Simon and Wolff, 1987).

All factors including ingredients, temperature, screw speed but feed rate have effects on color changes (Badrie and Mellowes, 1991; Gujska and Khan, 1991; Ilo et al., 1999; Liu et al., 2000; Altan et al., 2008a; Altan et al., 2008b; Santosa et al., 2008). Increase in the expansion of the extrudates gives more bright color in the extrudates due to the presence of air cells instead of a compact structure (Altan et al., 2008a). Therefore, changes in color is directly related with the factors affecting the expansion of the extrudates. Moreover, there are many reactions that affect color during extrusion cooking (Ilo et al., 1999). Pigment degradation is one of them and the non-enzymatic browning reactions are the others (Ilo et al., 1999). The factors that enhance the browning reations such as caramelization and maillard reaction, affects the color of the extrudates.

Caramelization is a non - enzymatic browning reaction which takes place in the presence of polyhydroxycarbonyl compounds (sugars, polyhydroxycarboxylic acids). Heating these compounds to relatively high temperatures results in a brown color and characteristic caramel flavor, in the absence of amino compounds. More energy is required for this process when compared to carbonylamino reactions, remaining other conditions equal (Hodge, 1953).

Maillard reaction is another non-enzymatic browning reaction during which a chemical reaction takes place between carbonyl groups of reducing sugars and amino groups of amino acids, peptides, or proteins, in the presence of heat (Yılmaz and Toledo, 2005; Eric et al., 2013). Maillard reaction ends up with development of characteristic food properties like color and flavor, and stability (Eric et al., 2013). In the presence of some water, it is favored by high temperature and by high concentrations or reactive groups (Potter and Hotchkiss, 1995).

Increasing screw speed decreases the residence time which means decreased heating time for the dough inside the extruder, and consequently results in lighter products (higher L* values) (Liu et al., 2000). On the other hand, increasing screw speed increases the shear. This would increase the product temperature, as a result of which the browning reactions are promoted and darker products are obtained (Liu et al., 2000). They are contradicting each other and the result depends on the dominance of one on another.

In the study of Liu et al. (2000), increasing the percentage of oat flour decreased the lightness and enhanced the redness values. In the same study, increasing the corn flour content resulted with an increase in the yellowness of the extrudates. These were related with carotenoid pigments where redness values of oat flour is higher and yellowness values of corn flour is higher (Liu et al., 2000).

Gujska and Khan (1991) reported that the lightness and redness of the extrudates were significantly decreased ($p \leq 0.05$) with increasing moisture content from 21% to 30%, for navy beans. Increasing the moisture content decreased the lightness of garbanzo and pinto bean extrudates, whereas the redness and yellowness were increased (Gujska and Khan, 1991). Badrie and Mellowes (1991) reported a decrease in the yellowness values of cassava extrudates with increasing feed moisture. Altan et al. (2008a) reported a decrease in lightness and and increase in the redness of the barley extrudates with the addition of tomato pomace and this was attributed to the lycopene pigment in the tomato pomace. In the other study of Altan et al. (2008b), increasing grape pomace level resulted in; reduced lightness, related with Maillard reaction; increased redness, related with Maillard reaction and destruction of heat sensitive pigment; increased yellowness, related with the presence of yellowish pigments in the pomace. Badrie and Mellowes (1992) reported an increase in yellowness of the extrudates with the addition of soybean flour.

Ilo et al. (1999) reported a decrease in the total color change of the extrudate with the increase in screw speed, which can easily explained by the decrease in residence time. Similarly, Badrie and Mellowes (1991) reported a decrease in yellow color of cassava extrudates with increasing screw speed. This was attributed to the reduced residence time. On the other hand, no significant effect of screw speed was observed in the lightness and the yellowness of the oat-corn puffs, whereas the redness of these extrudates was significantly effected from the changes in the screw speed (200, 300, and 400rpm) (Liu et al., 2000).

Synergistic effects play an impotant role in the color changes, that is why it would not be easy to comment on the effect of any single factor on color changes without considering all the others.

1.3.4.4 Texture

Hardness and fracturability (brittleness) are two parameters mostly used to investigate the textural properties of the extrudates. As hardness defines the maximum force required to break the extrudates in the first compression, fracturability indicates the distance to break the extrudate. Low values for hardness and fracturability are desired for snacks (Mendonça et al., 2000; Yanniotis et al., 2007). Expansion characteristics are determinative on textural properties of the extrudates. As the overall expansion or porosity values are high, which also means reduced bulk density, the extrudates are easier to break, thus, hardness and fracturability values are low (Mendonça et al., 2000; Yanniotis et al., 2007).

Hardness and fracturability is positively correlated with the bulk density and negatively correlated with sectional expansion index (Altan et al., 2008a; Altan et al., 2009). Altan et al. (2008b) indicated that the temperature is the main factor affecting the bulk density of the extrudates with a greater extent. Jin et al. (1995) suggested that the product texture is related with the cell wall thickness of the extrudates. More force is required for breaking the thicker cell walls which means higher hardness values. Reduction in the expansion ratio of the extrudates make them more dense in radial section and consequently, the breaking strenght increases. Jin et al. (1995) also suggested an inversely correlation between the diameter of the extrudates and the breaking strength ($r = 0.904$, $p \leq 0.001$). Ingredients, temperature, screw speed, feed rate and screw configuration are determinative on the textural properties of the extrudates (Moore et al., 1990; Badrie and Mellowes, 1991; Chen et al., 1991; Jin et al., 1995; Ilo et al., 1999; Liu et al., 2000; Mandonça et al., 2000; Ding et al., 2005; Ding et al., 2006; Yanniotis et al., 2007; Altan et al., 2008a; Altan et al., 2008b; Altan et al., 2009).

1.3.4.4.1 Ingredients

Several researchers reported that increasing feed moisture increased the hardness and fracturability of the extrudates (Badrie and Mellowes, 1991; Mandonça et al., 2000; Liu et al., 2000; Ding et al., 2005; Ding et al., 2006). Liu et al. (2000) proposed that increase in the moisture content decreased the expansion of the oat-corn puff and this was the reason of the increase in hardness and fracturability. In addition, Ding et al. (2006) indicated that increasing feed moisture causes a decrease in expansion and an increase in bulk density, so does in hardness values.

Increasing fiber content also causes an increases in the hardness and fracturability of the extrudates (Moore et al., 1990; Jin et al., 1995; Ilo et al., 1999; Liu et al., 2000; Yanniotis et al., 2007; Altan et al., 2008a; Altan et al., 2008b). As the presence of fibers causes premature rupture of air cells before they reach to their maximum potential and less porous structure is obtained, hardness values of the extrudates increases (Lue et al., 1991; Yanniotis et al., 2007). Jin et al. (1995) suggested that addition of fibers results in small cell sizes but thicker cell walls and this increases the force needed to break the extrudate which means higher hardness values.

1.3.4.4.2 Temperature

Several researchers reported that increasing temperature decreases the hardness (Ilo et al., 1999; Mendonça et al., 2000; Ding et al., 2005; Ding et al., 2006; Altan et al., 2008a; Altan et al., 2008b). This was found positively correlated with bulk density (Altan et al., 2008b). However, Chen et al. (1991) reported an increase in hardness values with increasing temperature. Ding et al. (2005) suggested that increasing temperature decreased the melt viscosity and increased the vapor pressure of water. This favors the bubble growth and as a result, more expanded, low density products are obtained with reduced hardness values.

1.3.4.4.3 Screw Speed

Several researchers reported that increasing screw speed resulted in a decrease in hardness and fracturability of the extrudates (Liu et al., 2000; Ding et al., 2006; Altan et al., 2008a). Liu et al. (2000) suggested that higher screw speeds may cause an increase in the product temperature. This promotes the expansion of the extrudates and thus decreased hardness and fracturability values.

1.3.4.4.4 Feed rate

In the study of Ding et al. (2005) and Ding et al. (2006), increasing feed rate significantly increased the hardness of the rice extrudates at low feed moisture, however at high feed moisture the increase in hardness with increasing feed rate was not significant.

1.3.4.5 Sensory Analysis

Appearance, texture and flavor are the quality factors that are determinative on the acceptibility of the products (Potter and Hotchkiss, 1995). These quality parameters can be measured by using instruments, however, acceptability is highly subjective subject since we respond to the products in terms of sensory, emotional, intellectual images and expectations (Hutchings et al., 2012). Hutchings (1999) also indicated that not only the receptor mechanisms affect the acceptability of the food, but also inherited and learned responces to specific events and immediate environment does matter on the motivation of buying something. Inherited and learned responces depends on the culture, fashion, physiology, preference, psychology and memory, whereas immediate environment would be affected from geographical factors, social factos and medical factors (Hutchings, 1999).

Sensitivity of people to detect the differences in sensory parameters may differ, as well. Falcone and Phillips (1988) proposed that there is no significant relationship between the objective and sensory mesurements of texture and inability of the panelists to distinguish between hardness and brittleness of the extrudates was given as the possible reason.

1.3.4.5.1 Appearance

Size, shape, wholeness and pattern can be important appearance factors (Potter and Hotchkiss, 1995). Lue et al. (1991) reported that extruded products with high fiber content were not appealing to the potential customers due to their reduced diameter, hard texture and rough, uneven surface. Similarly, Liu et al. (2000) reported negative appearance attributes such as roughness, compactness, dryness, curving and irregularness for the extrudates with high percentage of oat. Color is also one of the important appearance factors since people considers color as an quality index and expects a certain taste of flavor based on them (Potter and Hotchkiss, 1995). In the study of Altan (2008a), the extrudates with tomato pomace (10%) had higher scores for acceptability of the extrudate based on color.

1.3.4.5.2 Texture

Mendonça et al. (2000) indicated that the general acceptability of the extruded products are based on texture rather than the appearance. Textural factors are related with the feel sensed by the fingers, the tongue, the palate or the teeth. There are expectations for the texture of a food and departure from the expected form is defined as quality defect (Potter and Hotchkiss, 1995). According to the study of Li et al. (2005) the products with higher fracturability values was prefered by the panelists instead of the products with lower fracturability.

1.3.4.5.3 Flavor

Flavor is the sum of sensations both perceived by the tongue and by the nose. The mixture of salt, sour, bitter and sweet tastes together with the characteristic aroma giving compounds are used to determine the flavor of a food (Potter and Hotchkiss, 1995). In the study of Altan et al. (2008a), increasing tomato pomace concentration resulted in higher flavor score for the extrudates.

1.3.4.5.4 Overall

Potter and Hotchkiss (1995) proposed that color and texture influence the judgements about flavor. Therefore, it is not possible to figure out the effect of only one factor on the acceptibility of a food since sensory analysis is highly subjective study. Altan et al. (2008a) reported that extrudates with tomato pomace had higher scores in sensory evaluation when compared to extrudates without tomato pomace. The overall acceptibility of the barley extrudates with different tomato pomace levels ranged between 3.94 and 5.23 out of 9.

CHAPTER 2

MATERIAL AND METHODS

2.1 MATERIALS

Corn grits were donated by Teknik Tarım (Manisa, Turkey). Tomatoes, red peppers and carrots were purchased from local groceries (Ankara, Turkey). Whole tomatoes (*Solanum lycopersicum L.*) were used in order to prepare the tomato pulps. After removing the stems and the seeds, tomatoes were feeded to the apple juicer (PRJ-3060, Premier, P.R.C) and crushed. The pulp and the juice, obtained, were combined in a container. Feed samples were prepared by mixing tomato pulp with corn grits to the moisture content of 25.15 ± 0.68% in a mixer (Kitchen Aid, Ariston, USA), for a time to ensure the homogenity of the feed material. The control was prepared by mixing corn grits with distilled water to the moisture content of 24.52 ± 0.20% in the same mixer.

Whole red pepper (*Capsicum annuum L.*) were used in order to prepare the red pepper pulps. After removing the stems and the seeds, red peppers were feeded to the apple juicer (PRJ-3060, Premier, P.R.C) and crushed. The pulp and the juice, obtained, were combined in a container. Feed samples were prepared by mixing red pepper pulp with corn grits to the moisture content of 25.07 ± 0.18% in a mixer (Kitchen Aid, Ariston, USA), for a time to ensure the homogenity of the feeding material. The control was prepared by mixing corn grits with distilled water to the moisture content of 24.98 ± 0.12% in the same mixer.

Whole carrots (*Daucus carota subs. sativus*) were used in order to prepare the carrot pulps. After removing the skins and the stems, carrots were feeded to the apple juicer

(PRJ-3060, Premier, P.R.C) and crushed. The pulp and the juice, obtained, were combined in a container. Feed samples were prepared by mixing carrot pulp with corn grits to the moisture content of 25.34 ± 0.06% in a mixer (Kitchen Aid, Ariston, USA), for a time to ensure the homogenity of the feeding material. The control was prepared by mixing corn grits with distilled water to the moisture content of 24.68 ± 0.16% in the same mixer.

The mixing ratios of the samples (corn grits and pulps) were determined according to the mass balance (moisture balance) while considering the desired final moisture content as 25%. Moisture contents of the ingredients (tomato pulp, red pepper pulp, carrot pulp and corn grits) and the samples were determined by using a halogen moisture analyzer at 160ºC (MX-50, AND, Japan). The samples were stored in a plastic bag at 4ºC, overnight. Samples were allowed to equilibrate at the room temperature for two hours just before the extrusion process.

2.2 METHODS

2.2.1 Extrusion

A laboratory scale co-rotating twin screw extruder in Figure 1 (Feza Gıda Müh. Makine Nakliyat ve Demir Tic. Ltd. Şti., İstanbul, Turkey) with computer control and data acquisition system was used for the study. The die diameter and the barrel length to diameter ratio (L:D) were 3mm and 25:1, respectively. 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 rotor speed. The feed was fed to the extruder with a twin screw volumetric feeder which was built into the extruder system.

Flow rate of the feed was 36 ± 1 g/min for all samples. Barrel temperature zones were set at 80ºC, 90ºC, 115ºC and 145ºC (die: 125ºC). After reaching steady state conditions, samples were taken only when actual measured barrel zone temperatures and die temperatures varried ±2ºC from the set temperatures. Collected extruded samples were cut into 5 cm pieces and dried at 50 ± 0.1ºC for 5 hr in an oven (ES500, nüve, Turkey). The final moisture contents of the dried samples were 6.87 ± 0.48% and 6.82 ± 0.37% for the samples with and without tomato pulp; 6.57 ± 0.18% and 6.64 ± 0.20% for the samples with and without red pepper pulp; 6.73 ± 0.08% and 6.73 ± 0.23% for the samples with and without carrot pulp, respectively. The dried samples were kept in a vacuum jar at room temperature until the analysis.

2.2.2 Bulk Density

Bulk densities of the extrudates were determined by using the Archimedes' principle which measures the volume of a solid, by measuring the volume of the liquid displaced after submerging. Weighted extrudates were submerged into previously melted paraffin (water-repellent substance) and then cooled. The paraffin covered product was weighed and submerged into the graduated cylinder filled with distilled water. Paraffin covered product was sinked with the help of marble with known volume. The rise in the level was noted and the bulk density was determined (Blake and Hartge, 1986). Five measurements were taken and avaraged.

$$m_{(paraffin)} = m_{(total)} - m_{(extrudate)} \quad (1)$$

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

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

$$\rho_{(extrudate)} = m_{(extrudate)} / V_{(extrudate)} \quad (4)$$

Where;

$m_{(paraffin)}$: Weight of the paraffin, used to cover the extruded sample (g)

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

$m_{(extrudate)}$: Weight of the extruded sample without paraffin (g)

$V_{(paraffin)}$: Volume of the paraffin, used to cover the extruded sample (cm^3)

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

$V_{(extrudate)}$: Bulk volume of the extrudate (cm^3)

$\Delta V_{(cylinder)}$: Volume displacement of the fluid in the cylinder (cm^3)

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

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

2.2.3 True Density (Particle Density)

True density analysis were performed at Middle East Technical University Central Laboratory by using helium pycnometer (Quantachrome Ultrapycnometer 1000, Florida, USA). Weighted extrudates were loaded into a chamber of known volume that was connected to a gas reservoir with the help of valve which was closed at first. The volume of the gas reservoir was also known and it was at higher pressure than chamber. Then, the valve was opened to allow gas to penetrate into the chamber. Knowing the initial and final pressures, true density was determined by using Boyle's law with the following equations.

$P_1V_1=P_2V_2$ (Boyle's Law) (5)

$P_i V_1 = P_f (V_1+V_2-V_{(true)})$ (6)

$\rho_{(true)} = m_{(extrudate)}/V_{(true)}$ (7)

Where;

P_i : Initial pressure at the first channel (atm)

P_f : Final pressure of the system after the valve was opened (atm)

V_1 : Volume of the first chamber (cm^3)

V_2 : Volume of the gas reservoir (cm^3)

$V_{(true)}$: True volume of the extrudates (cm^3)

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

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

2.2.4 Sectional Expansion Index (SEI)

Thirty pieces of 5cm cut extrudates, from each treatment, were chosen at random. Diameters of the extrudates were measured with a digital caliper at random places and the average was taken. Sectional expansion index that can also be expressed as radial expansion was calculated according to the following equation (Alvarez-Martinez et al., 1988; Pai et al., 2009).

$SEI = (D_e/D_d)^2$ (8)

Where ;

D_e : Diameter of the extrudate (mm)

D_d : Diameter of the die (mm)

2.2.5 Volume Expansion Index (VEI)

Volume expansion index that can also be expressed as overall expansion was calculated according to the following equation (Ali et al., 1996; Pai et al., 2009);

$$VEI = \rho_{(true)} / \rho_{(extrudate)} \quad (9)$$

Where ;

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

$\rho_{(extrudate)}$: Bulk density of the extrudates (g/cm^3)

2.2.6 Longitudinal Expansion Index (LEI)

Longitudinal expansion index that can be expressed as axial expansion was calculated by dividing overall expansion to radial expansion according to the following equation (Ali et al., 1996; Pai et al., 2009);

$$LEI = VEI / SEI \quad (10)$$

Where ;

LEI : Longitidunal expansion index

VEI : Volume expansion index

SEI : Sectional expansion index

2.2.7 Porosity

Porosity was calculated according to the following formula. Results were given as the avarage of five samples.

$$\text{Porosity} = 1- \rho_{(extrudate)} / \rho_{(true)} \qquad (11)$$

Where ;

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

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

2.2.8 Scanning Electron Microscopy (SEM)

Scanning electron microscopy analysis were performed at the Middle East Technical University Central Laboratory. Scanning electron microscope (400F Field Emission, QUANTA, Holland) was used to view the extrudates in three dimensions and to determine the shape and surface features of the extruded products. Exrudates with and without pulp were coated with 5 nm Au-Pd by sputter coater (Polaron, Range, UK) before the scanning process.

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

The water absorption index and water solubility index were determined according to Anderson et al. (1969). The extrudates were ground with a grinding machine (KSW 445 CB, Bomann, Germany) and passed through a mesh sieve, 212 micron (200 M.M B.S, Endecotts Ltd, London), prior to analysis. 1 g of sample was suspended in 6 ml of distilled water and gently stirred at 1000 rpm on magnetic stirrer (Wisd WiseStir MS-20D, Witeg, Germany) for 30 min at 30ºC temperature. Subsequently, the dispersions were centrifuged (2-16PK, Sigma Laborzentrifugen, Germany) at 24ºC and 4000xg for 20 min. The supernatants were poured into preweighted petri dishes and dried overnight at 110ºC to remove water. Experiments were replicated six times. WAI and WSI were calculated as follows :

$$WAI\ (g/g) = m_{sediment} / m_{dry} \quad (12)$$

$$WSI\ (\%) = (m_{dissolved} / m_{dry})*100 \quad (13)$$

Where ;

$m_{(sediment)}$: Weight of sediment after removal of the supernatant (g)

$m_{(dry)}$: Dry weight of original solid sample (g)

$m_{(dissolved)}$: Dry weight of dissolved solids in supernatant (g)

2.2.10 Color

The extrudates were grounded in a grinding machine (KSW 445 CB, Bomann, Germany) and passed through a mesh sieve, 212 micron (200 M.M B.S, Endecotts Ltd, London), prior to analysis. The sieved particles put in the sample holder and were pressed gently as there would not be a space between them. A colorimeter (CR-10, Konica minolta, Japan) was used to determine color values of the grounded extruded samples in terms of lightness, redness and yellowness (L*, a* and b* values). The measurements were taken under the conditions of standard illuminant D65 and 10º observer. The colorimeter was calibrated against a standard white (L*= 93.8, a*= 0.0, b*= 5.2). For each sample 10 measurements were taken and averaged.

2.2.11 Texture

A texture analyzer (TA.XTPlus, Stable Micro Analyser, UK) was used in compression mode to record the required force to break extruded products. Hardness, the peak force of the first compression of the product, and fracturability, the point where the plot has its first significant peak (where the force falls off) during the probe's first compression, was recorded. The extruded sample (4 cm long) was placed on three point bend rig which has two adjustable supports. These supports were fixed 1 cm away from the center and texture analyzer was operated in the compression mode with a sharp testing blade (0.12 cm thick, 8 cm wide). The analyzer head moved the probe down at a rate of 1.00 mm/s until it broke the extrudates. Break sensitivity was 10.0 g, trigger force was 5.0 g. Calibration was conducted before the analysis. Analysis was repeated for twenty five extrudate sample pieces.

2.2.12 Sensory

Nine panelists from Food Engineering Departmant master students evaluated the extruded snacks. Definitions of the attributes were presented and the proposed score sheet was explained before the panel. Panelists were asked to evaluate the extruded snacks for apperance, color, hardness, crispiness, porosity and overall preference on a 9 point hedonic scale (1: Dislike extremely to 9: Like extremely). Panelists rinsed their mouths with water between tasting the samples.

2.2.13 Determination of Dietary Fiber

Soluble and insoluble dietary fibre content of the corn grit, tomato pulp, red pepper pulp and carrot pulp were determined according to AOAC Method 991.43 (1992). 40 mL of previously prepared MES-TRIS buffer solution was added to 1 ± 0.005 g of samples and stirred until completely dispersed. Blanks were prepared by not adding sample in MES-TRIS buffer solution. Then, solution digested sequentially with heat-stable α-amylase at 95 ± 1ºC, protease at 60 ± 1ºC, and amyloglucosidase at 60 ± 1ºC. Enzyme digestes were filtered thorough tared fritted glass crucibles (por.3) with the help of pump (Millipore, WP6122050 A). Crucibles containing insoluble dietary fiber were rinsed twice with 10 mL of dilute alcohol (95%) followed by acetone. Filtrates were saved for soluble dietary fiber analysis and crucibles were dried overnight in a 105 ± 1ºC oven. Filtrates were then mixed with 4 volume of 95% of ethanol preheated to 60ºC to precipitate materials that were soluble in the digestates. 1 h after, precipitates were filtered through tared fritted glass crucibles (por.3) with the help of pump (Millipore, WP6122050 A). Crucibles containing soluble dietary fiber were rinsed twice with 15 mL of 78% ethanol, 95% ethanol and acetone, respectively. Crucibles were then dried overnight in a 105 ± 1ºC oven.

One of each set of duplicate insoluble and soluble fiber residues was ashed in a muffle furnace at 525 ± 1ºC for 5 hour. Another set of residues was used to determine protein as Kjeldahl nitrogen 6.25. Soluble or insoluble dietary fiber contents were determined according to Equation 15. Total dietary fiber was calculated as the sum of soluble and insoluble dietary fiber.

$$B = (BR_1+BR_2)/2 – BP - BA \quad (14)$$

Where ;

BR_1 : residue weight of blank 1 (g)

BR_2 : residue weight of blank 2 (g)

BA : ash weight from blank residue 1 (g)

BP : protein weight from blank residue 2 (g)

$$\text{Dietary fibre (\%)} = [(R_1+R_2)/2 – P – A – B] / [(m_1+m_2)/2] \times 100 \quad (15)$$

Where;

m_1 : weight of sample 1 (g)

m_2 : weight of sample 2 (g)

R_1 : residue weight 1 from m_1 (g)

R_2 : residue weight 2 from m_2 (g)

A : ash weight from R_1 (g)

P : protein weight from R_2 (g)

B : blank content calculated from equation 14 (g)

2.2.14 Statistical Analysis

All the results were analyzed by one-way analysis of variance (ANOVA) by using data analysis function of the Microsoft Office Excell 2007. Differences at $p \leq 0.05$ were considered as significant difference.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 EXPANSION CHARACTERISTICS

The size, number and distribution of the air cells, bubbles, are primary determinative factors for the expansion characteristics of the extrudates (Lue et al., 1990). These bubbles are generated due to the pressure difference between the die and exterior of the die, which are, respectively, at high pressure and atmospheric pressure. Leaving the die, extrusion cooked melt suddenly face with pressure drop that causes a flash off of internal moisture and hence, nucleation and expansion of the bubbles in the molten extrudate. Porous, sponge like structure is obtained within the extrudate due to the air cells generated, whose size, number and distribution determines the expansion of the extrudates in both radial and longitudinal direction (Moraru and Kokini, 2003; Arhaliass et al., 2003).

As well as the pressure drop, rheological properties of the melt influence the size, number and distribution of the bubbles, hence, the expansion characteristics of the extrudates. Melt elasticity influences the expansions in the radial direction and melt viscosity influences the expansions in the longitudinal direction (Launay and Lisch, 1983). Sectional expansion index (SEI), longitudinal expansion index (LEI), volume expansion index (VEI), bulk density and porosity data were investigated to understand the degree of puffing by the extrusion of cooked melt.

3.1.1 Tomato Pulp

Sectional expansion indexes of the corn grit extrudates were 5.54 ± 0.82 (m^2/m^2) and 6.45 ± 0.98 (m^2/m^2) for with and without tomato pulp, respectively, and these values describe the expansion in the radial direction. Analysis of variance showed statistically significant decrease in SEI value with the addition of tomato pulp (Table 1). Similar results were obtained by other researchers.

Sugar beet fiber and corn meal were used in the study of Lue et al. (1991) and less radial expansion was obtained as a result of increasing the percentage of sugar beet fiber. Lue et al. (1991) suggested that the presence of fiber particles tended to rupture the cell walls before the gas bubbles had expansed to their full potential.

Ilo et al. (1999) studied with rice flour and amaranth blends, and found out that increasing the amaranth content also decreased the sectional expansion index of the extrudates. This was attributed to the fact that amaranth content affects the extent of starch gelatinization and the rheological properties of the extrusion cooked melt. Shrinkage of the expanded extrudate was considered as an other possible explanation of this phenomenon (Fan et al., 1996, Ilo et al. 1999).

Altan et al. (2008a) used blends of barley flour and tomato pomace. Increasing the percentage of tomato pomace in the study, resulted in decreasing sectional expansion index of the extrudates and this was attributed to dilution effect of pomace on starch (Altan et al., 2008a). The barley flour and grape pomace blends were used for another study of Altan et al. (2008b) and found out similar results. Increasing the percentage of pomace up to 6% decreased sectional expansion index of the extrudates (Altan et al., 2008b). Several researchers have indicated that the expansion ratio of extruded cereals depends on the degree of starch gelatinization (Chinnaswamy and Hanna, 1988; Case et al., 1992). Starch is the dominant polymer in most cereal systems and other ingredients such as protein, sugars, fats, and fiber act as diluents (Moraru and Kokini, 2003). The source and the amount of the dietary fiber are determinative on the expansion of the extrudates (Lue et al., 1990).

Longitudinal expansion indexes of the extrudates with and without tomato pulp were 0.94 ± 0.10 (m^2/m^2) and 0.89 ± 0.05 (m^2/m^2), respectively, which showed no statistically significant difference with tomato pulp addition. Longitudinal expansion index describes the expansion in the axial direction. Launay and Lisch (1983) proposed that melt viscosity influences the expansion in the longitudinal direction. Based on these, no change in the LEI value with the addition of tomato pulp may be attributed to the fact that added amount of tomato pulp had no effect on melt viscosity.

Sectional expansion index and longitudinal expansion index consider expansion only in one direction, so it would not be correct to comment about expansion characteristics of the tomato pulp added extrudates without considering volume expansion index, bulk density and porosity values, which consider expansion in all directions.

Volume expansion indexes were 5.21 ± 0.53 (m^3/m^3) and 5.73 ± 0.32 (m^3/m^3) for the corn grit extrudates with and without tomato pulp addition, respectively (Table 1). Volume expansion index is the product of sectional expansion index and longitudinal expansion index, hence the factors affecting these two expansion indices should in turn affect VEI (Alvarez-Martinez et al., 1988; Falcone and Phillips, 1988). Bulk densities were 0.292 ± 0.029 (g/cm^3) and 0.278 ± 0.014 (g/cm^3) and porosity values were 0.81 ± 0.02 and 0.83 ± 0.01 for the corn grit extrudates with and without tomato pulp, respectively (Table 1). No statistically significant difference was observed for volume expansion index, bulk density and porosity values with tomato pulp addition. Since all volume expansion index, bulk density and porosity describes the overall expansion, parallel results were expected.

Table 1. Physical properties of the extrudates, with and without tomato pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Tomato Pulp Added
SEI	6.45 ± 0.98[a]	5.54 ± 0.82[b]
LEI	0.89 ± 0.05[a]	0.94 ± 0.10[a]
VEI	5.73 ± 0.32[a]	5.21 ± 0.53[a]
Bulk Density	0.278 ± 0.014[a]	0.292 ± 0.029[a]
Porosity	0.83 ± 0.01[a]	0.81 ± 0.02[a]

Bulk Density results are means ± SD (n= 5); SEI results are means ± SD (n= 30); VEI results are means ± SD (n= 5); LEI results are means ± SD (n= 5); Porosity results are means ± SD (n= 5); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.1.2 Red Pepper Pulp

Sectional expansion indexes of the corn grit extrudates with and without red pepper pulp were 5.80 ± 0.72 (m^2/m^2) and 5.84 ± 0.74 (m^2/m^2), respectively, which showed no statistically significant difference with the addition of red pepper pulp (Table 2). Launay and Lisch (1983) proposed that melt elasticity influences the expansion in the radial direction. Based on these, no change in the SEI value with the addition of red pepper pulp may be attributed to the fact that added amount of red pepper pulp had no effect on melt elasticity.

Longitudinal expansion indexes of the extrudates with and without red pepper pulp addition were 0.86 ± 0.02 (m^2/m^2) and 1.14 ± 0.05 (m^2/m^2), respectively, which showed statistically significant decrease with red pepper pulp addition (Table 2). Launay and Lisch (1983) proposed that melt viscosity influences the expansion in the longitudinal direction. Based on these, change in the LEI value with the addition of red pepper pulp may be attributed to the fact that added amount of red pepper pulp had an effect on melt viscosity.

Although there was no statistically significant difference in SEI values with the addition of red pepper pulp, statistically significant difference was observed in all volume expansion index, bulk density and porosity values. Similar results were obtained by other researchers.

The study of Phillips et al. (1984) had shown that the expansion ratio and bulk density might not be related to each other and this was explained by the fact that sectional expansion index considers expansion only in the radial direction, whereas bulk density considers expansion in all directions (Falcone and Phillips, 1988).

Being the product of sectional expansion index and longitudinal expansion index, the factors affecting sectional and longitudinal expansion indexes should in turn affect VEI (Alvarez-Martinez et al., 1988; Falcone and Phillips, 1988). Volume expansion indexes of the corn grit extrudates with and without red pepper pulp were 4.97 ± 0.12 (m^3/m^3) and 6.66 ± 0.29 (m^3/m^3), respectively (Table 2). According to the ANOVA results, there was a decrease in VEI values with red pepper pulp addition.

There is an inverse relation between bulk density and overall expansion. Bulk densities were 0.296 ± 0.007 (g/cm^3) and 0.230 ± 0.010 (g/cm^3) for the corn grit extrudates with and without red pepper pulp, respectively (Table 2), which showed an increase with the addition of red pepper pulp. This was expected since there was a decrease in volume expansion index with the addition of red pepper pulp.

Similar results were obtained in the study of Altan et al. (2008b). Increase in the level of grape pomace resulted with an increase in bulk density and this was attributed to the presence of fiber particles (Altan et al., 2008b). Fiber particles tended to rupture the cell walls before the gas bubbles had expanded to their full potential (Lue et al., 1991). On the other hand, bulk density of barley flour and tomato pomace were found not to be significantly depend on pomace level (Altan et al., 2008a).

Porosity values of the corn grit extrudates with and without red pepper pulp were 0.80 ± 0.01 and 0.85 ± 0.01, respectively (Table 2), which showed a decrease with the addition of red pepper pulp. Similar result was obtained in the study of Yanniotis et al. (2007), in which the presence of wheat fiber decreased the porosity of the extrudates, significantly ($p \leq 0.05$), and it was attributed to the fibers that cause premature rupture of bubbles.

Table 2. Physical properties of the extrudates, with and without red pepper pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Red Pepper Pulp Added**
SEI	5.84 ± 0.74^{a}	5.80 ± 0.72^{a}
LEI	1.14 ± 0.05^{a}	0.86 ± 0.02^{b}
VEI	6.66 ± 0.29^{a}	4.97 ± 0.12^{b}
Bulk Density	0.230 ± 0.001^{a}	0.296 ± 0.007^{b}
Porosity	0.85 ± 0.01^{a}	0.80 ± 0.01^{b}

Bulk Density results are means ± SD (n= 5); SEI results are means ± SD (n= 30); VEI results are means ± SD (n= 5); LEI results are means ± SD (n= 5); Porosity results are means ± SD (n= 5); values of the same row, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

3.1.3 Carrot Pulp

Analysis of variance showed no statistically difference on any of the physical properties like sectional expansion index, longitudinal expansion index, volume expansion index, bulk density and porosity value of the corn grit extrudates with and without carrot pulp (Table 3).

It is known that expansion characteristics depend on the degree of gelatinization, hence starch is the main component in expansion phenomena (Case et al., 1992; Chinnaswamy and Hanna, 1988; Moraru and Kokini, 2003). Moraru and Kokini (2003) have demostrated that the ingredients other than starch, such as protein, sugars, fats and fiber act as diluents. However, based on the results of the study, addition of the carrot pulp had no significant effect on the expansion. This may be attributed to addition of carrot pulp, in the studied amount, has not significantly affect the rheological properties of the melt or there might not be enough fiber to rapture the cell wall.

Table 3. Physical properties of the extrudates, with and without carrot pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Carrot Pulp Added
SEI	6.38 ± 1.00[a]	5.96 ± 0.83[a]
LEI	0.87 ± 0.04[a]	0.87 ± 0.07[a]
VEI	5.55 ± 0.28[a]	5.18 ± 0.44[a]
Bulk density	0.273 ± 0.014[a]	0.296 ± 0.007[a]
Porosity	0.82 ± 0.01[a]	0.80 ± 0.01[a]

Bulk Density results are means ± SD (n= 5); SEI results are means ± SD (n= 30); VEI results are means ± SD (n= 5); LEI results are means ± SD (n= 5); Porosity results are means ± SD (n= 5); values of the same row, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

3.2 SCANNING ELECTRON MICROSCOPY

The scanning electron micrographs gives information about the internal structure of the extruded products. Jin et al. (1995) reported less expanded and more compact extrudates with increasing fiber content and this was coherent with scanning electron micrographs since smaller air bubbles and thicker cell walls were observed with increasing fiber level from 10% to 30%. In our study, SEM results indicated no apparent difference with the addition of tomato, red pepper and carrot pulp. This could be due to the fiber content. The fiber level in the pulps was not enough to make changes in the structure of the extrudates. Figure 5, 6 and 7 shows scanning electron microscopy images of extrudates with and without pulp for tomato, red pepper and carrot pulps, respectively.

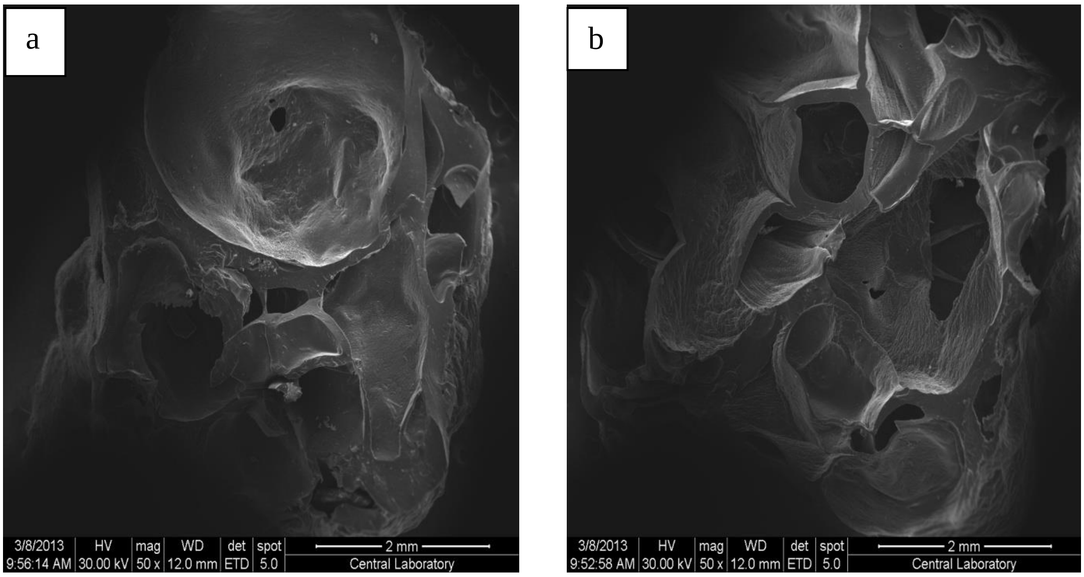

Figure 5. a) Corn grit extrudate with tomato pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X. **b)** Corn grit extrudate without tomato pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X.

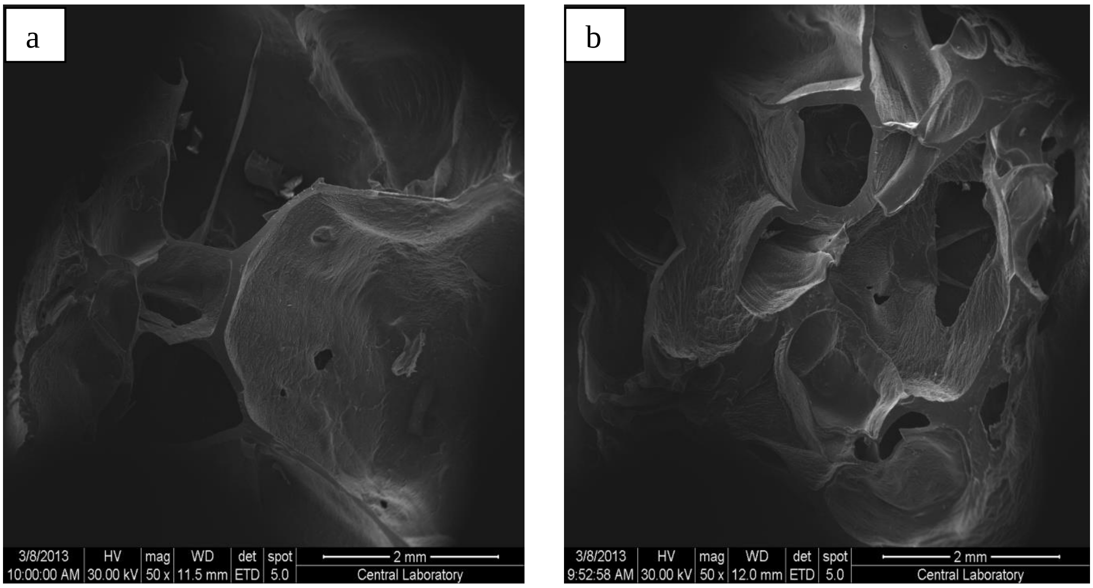

Figure 6. a) Corn grit extrudate with red pepper pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X. **b)** Corn grit extrudate without red pepper pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X.

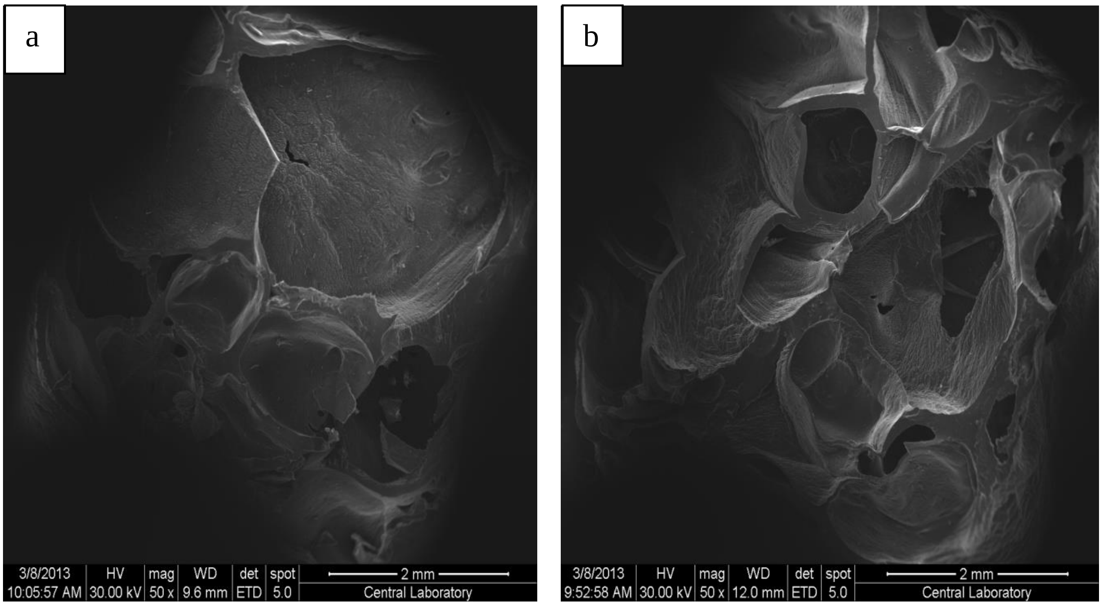

Figure 7. a) Corn grit extrudate with carrot pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X. **b)** Corn grit extrudate without carrot pulp (extruded at 145ºC, 175 rpm, 25% moisture), 50X.

3.3 WATER ABSORPTION INDEX AND WATER SOLUBILITY INDEX

The water absorption index (WAI) measures the volume occupied by the granule or starch polymer after swelling in excess water (Sriburi and Hill, 1999). Anderson et al. (1969) indicated that it can be used as an index of gelatinization. The water solubility index (WSI) measures the amount of free polysaccharide or polysaccharide released from the granule on addition of excess water (Sriburi and Hill, 1999). Kirby et al. (1988) stated that it can be used as an indicator of degradation of molecular components. WAI and WSI are important parameters in defining the quality of the extruded products and give information about possible behaviour of the materials, in the case of further processing (Sriburi and Hill, 1999). There is a inversely proportional relation between them.

WAI depends on the presence of undamaged polymer chains, availability of the hydrophilic groups and the gel forming capacity of the macromolecules (Gomez and Aguilera, 1983). Starch gelatinization, protein denaturation and swelling of the raw fiber, all, could be responsible for the increase in WAI of the extrudates (Singh et al., 2007a). On the other hand, an increase in WSI demonstrates an increase in starch conversion (Sriburi and Hill, 1999).

Fiber was found to have significant effect on both WAI and WSI (Artz et al., 1990; Jin et al., 1995; Hashimoto and Grossmann, 2003; Singh et al., 2007a; Altan et al., 2008a). Artz et al. (1990) reported a decrease in WAI of the extrudates with the increase in fiber concentration, in most instances, particularly at high pH (pH 11) and elevated processing temperatures (90ºC-150ºC). The highest WAI was held at 100% starch which was an expected result for them since temperature increase favors the starch gelatinization and addition of fiber dilutes the starch concentration. Even at high fiber concentrations, decreasing the shear rate from 500 rpm to 200 rpm, at pH 11, resulted with an increase in WAI with an increase in extrusion temperature. Residence time increases at low shear rates and because of this, there might have been sufficient time to complete gelatinization of starch; besides the possibility of hydrolysis took place in cellulose or hemicellulose (Artz et al., 1990).

In the study of Singh et al. (2007a), incorporation of pea grits in the feed material resulted with a decrease in WAI of the rice grit extrudates in the study conditions (feed moisture: 18-24%; temperature: 130ºC-170ºC; pea grit level: 0-30%), and the result was attributed to the dilution of starch in pea blend. It was also reported that WSI of the rice grits was also significantly affected from the addition of pea grits. This was explained by the change in composition of the feed with the addition of pea grits, since fiber, starch and protein has effect on WSI (Jones et al., 2000; Singh et al., 2007a).

Altan et al. (2008a) also reported a significant decrease ($p \leq 0.01$) in the WAI of the barley extrudates with increasing the tomato pomace level (2-10%) in the study conditions (temperature: 140ºC - 160ºC; screw speed: 150rpm - 200rpm). This was attributed to the dilution of starch with the addition of tomato pomace and the competition of absorption of water between pomace and starch.

According to the study of Jin et al. (1995), increasing fiber content up to 20% resulted with a decrease in WAI and an increase in WSI of the corn meal extrudates, while further increasing of the fiber content (from 20% to 40%) resulted with an increase in WAI and a decrease in WSI of the corn meal extrudates. Jin et al. (1995) suggested a correlation between WAI and bulk density ($r=0.99$, $p\leq0.01$); WSI and specific volume ($r=0.59$, $p\leq0.01$) and concluded that WAI and WSI are related to the expansion of extrudate based on the expansion results of the same study.

Similarly, Hashimoto and Grossmann (2003) reported an increase in WAI of cassava bran/cassava starch extrudates, with increasing the cassava bran content (10-50%). This was attributed to the increased level of fiber and its high water absorption capacity. Badrie and Mellowes (1992) also reported an increase in WAI and decrease in WSI of the cassava extrudates as a result of wheat bran addition to cassava flour. Hashimoto and Grossmann (2003) suggested that structural modifications would be responsible for this result, since the modification might have promoted interactions between fiber and starch, reducing solubility.

3.3.1 Tomato Pulp

Water absorption indexes were 4.56 ± 0.26 ($g.g^{-1}$) and 4.71 ± 0.31 ($g.g^{-1}$); water solubility indexes were $10.88 \pm 2.33\%$ and $11.82 \pm 3.01\%$ for the corn grit extrudates with and without tomato pulp. Analysis of variance indicated that tomato pulp addition did not affect water absorption and water solubility indexes, significantly ($p\leq0.05$) (Table 4).

Table 4. Water absorption and water solubility indexes of the extrudates, with and without tomato pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Tomato Pulp Added
WAI ($g.g^{-1}$)	4.71 ± 0.31 [a]	4.56 ± 0.26 [a]
WSI (%)	11.82 ± 3.01 [a]	10.88 ± 2.33 [a]

WAI and WSI results are means ± SD (n= 6); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.3.2 Red Pepper Pulp

Water absorption indexes were 4.76 ± 0.33 ($g.g^{-1}$) and 4.79 ± 0.13 ($g.g^{-1}$); water solubility indexes were 10.88 ± 2.39% and 9.58 ± 0.94% for the corn grit extrudates with and without red pepper pulp. According to these results, red pepper pulp addition did not affect water absorption and water solubility indexes, significantly (Table 5).

Table 5. Water absorption and water solubility indexes of the extrudates, with and without red pepper pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Red Pepper Pulp
WAI ($g.g^{-1}$)	4.79 ± 0.13 [a]	4.76 ± 0.33 [a]
WSI (%)	9.58 ± 0.94 [a]	10.88 ± 2.39 [a]

WAI and WSI results are means ± SD (n= 6); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.3.3 Carrot Pulp

Water absorption indexes were 4.38 ± 0.17 (g.g^{-1}) and 4.49 ± 0.05 (g.g^{-1}); water solubility indexes were 13.53 ± 1.31% and 12.93 ± 0.67% for the corn grit extrudates with and without tomato pulp. Analysis of variance showed no significantly difference for water absorption index with the addition of carrot pulp (Table 6).

Table 6. Water absorption and water solubility indexes of the extrudates, with and without carrot pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Carrot Pulp Added
WAI (g.g^{-1})	4.49 ± 0.05 [a]	4.38 ± 0.17 [a]
WSI (%)	12.93 ± 0.67 [a]	13.53 ± 1.31 [a]

WAI and WSI results are means ± SD (n= 6); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

In our study, concentration of the fiber was not high enough to make changes in the concentration of the starch or dilute the starch. Extrusion conditions gave sufficient time to completely gelatinize the amount of starch associated with fiber.

3.4 COLOR

Color is an important characteristic of a food material which is directly related to the acceptability of food products. It is used as an index of quality since people expect a certain taste of flavor, based on color. In addition, changes in color during processing can provide information about the degree of thermal treatment (Chen et al, 1991).

Extrusion is a high temperature - short time process, during which many reactions take place that affect color (Ilo et al., 1999). Decomposition of the heat sensitive pigments due to high temperature is one of the three major reasons, whereas color fading due to product expansion is another (Berset, 1989) and the last is color formations as a result of chemical reactions such as caramelization of carbohydrates, the Maillard reaction and the effects of oxidative decomposition products of lipids and proteins (Dworschak and Carpenter, 1980).

The components of CIE Lab, L*, a* and b* gives information about lightness, redness-greenness and blueness-yellowness of the extrudates, respectively.

3.4.1 Tomato Pulp

Analysis of variance showed significantly difference ($p \leq 0.05$) in all color parameters, L*, a* and b* (Table 7). L* values were 79.18 ± 0.35 and 79.55 ± 0.35; a* values were 7.11 ± 0.43 and 2.05 ± 0.08; b* values were 37.78 ± 1.12 and 36.03 ± 1.24 for the corn grit extrudates, with and without tomato pulp, respectively (Table 7).

Significant decrease ($p \leq 0.05$) was observed in L* values with the addition of tomato pulp, while there was a significant increase ($p \leq 0.05$) in a* and b* values of the corn grit extrudates.

The increase in redness (a* value) of the extrudates was due to the presence of the lycopene and increase in yellowness (b* value) was due to the presence of lutein and β-carotene together, in tomatoes. Lycopene is the pigment responsible for the red color of the tomatoes which comprises 90% of the pigments in tomato, whereas the β-carotene and lutein comprises small amounts (≤ 5%) (Barrett and Anthon, 2008; Lin and Chen, 2003). β-carotene imparts a light yellow to orange color and lutein imparts yellow color (DeMan, 1990).

Table 7. Color properties of the extrudates with and without tomato pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Tomato Pulp Added**
L*	79.55 ± 0.35 [a]	79.18 ± 0.35 [b]
a*	2.05 ± 0.08 [a]	7.11 ± 0.43 [b]
b*	36.03 ± 1.24 [a]	37.78 ± 1.12 [b]

L*,a*,b* results are means ± SD (n= 10); values of the same row, followed by the same letter (a,b) are not statistically different (p≤0.05).

3.4.2 Red Pepper Pulp

L* values were 75.84 ± 0.46 and 81.50 ± 0.44; a* values were 11.78 ± 0.38 and 1.80 ± 0.34; b* values were 41.05 ± 0.72 and 34.55 ± 0.79 for the corn grit extrudates with and without red pepper pulp, respectively (Table 8). Analysis of variance showed significant difference ($p \leq 0.05$) in all color parameters, L*,a* and b* (Table 8).

Significant decrease ($p \leq 0.05$) was observed in L* values of the corn grit extrudates with the addition of red pepper pulp, while there was a significant increase ($p \leq 0.05$) in a* and b* values of the corn grit extrudates. The increase in redness (a* value) of the extrudates could be due to the presence of capsanthin and capsorubin in the red bell peppers (Minquez-Mosquera et al., 2008). They are the carotenoids responsible for the red color which comprises 35% and 6% of the total carotenoids in red bell peppers, respectively (Curl, 1962).

The increase in yellowness (b* value) of the extrudates could be due to the presence of β-carotene, violaxanthin, cryptoxanthin, zeaxanthin, antheraxanthin, β-cryptoxanthin and cucurbitaxanthin A (Minquez-Mosquera et al., 2008). They are the carotenoids responsible for the yellow color which comprises 10%, 10%, 6%, ≤2%, ≤2%, ≤2% and ≤2% of the total carotenoids in red bell peppers, respectively (Curl, 1962).

Table 8. Color properties of the extrudates with and without red pepper pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Red Pepper Pulp Added**
L*	81.50 ± 0.44 [a]	75.84 ± 0.46 [b]
a*	1.80 ± 0.34 [a]	11.78 ± 0.38 [b]
b*	34.55 ± 0.79 [a]	41.05 ± 0.72 [b]

L*,a*,b* results are means ± SD (n= 10); values of the same row, followed by the same letter (a,b) are not statistically different ($p \leq 0.05$).

3.4.3 Carrot Pulp

L* values were 79.60 ± 0.45 and 81.19 ± 0.33; a* values were 3.01 ± 0.17 and 2.09 ± 0.35; b* values were 39.64 ± 0.63 and 35.75 ± 1.34 for the corn grit extrudates with and without carrot pulp, respectively. (Table 9). Analysis of variance showed significant difference ($p \leq 0.05$) in all color parameters, L*, a* and b* (Table 9).

Significant decrease ($p \leq 0.05$) was observed in L* values of the corn grit extrudates with the addition of carrot pulp, while there was a significant increase ($p \leq 0.05$) in a* and b* values of the corn grit extrudates. The increase in redness (a* value) and yellowness (b* value) was due to the presence of carotenoids in carrot which are mainly α-carotene and β-carrotene. ɣ-carotene, ζ-carotene, β-zeacarotene and lycopene are found in carrots as well, even they are in smaller amounts (Simon and Wolff, 1987). α-carotene impacts a light to reddish orange color, β-carotene impacts a light yellow to orange color whereas ζ- carotene impacts orange red to red color (DeMan, 1990).

The reduction in the lightness (L* value) of the corn grit extrudates with pulp addition can be explained by various reasons. Altan et al. (2008a) has indicated that the increase in expansion gives more bright color in the extrudate due to the presence of air cells instead of dull color. Expansion of the corn grit extrudates, in this study, has significantly decreased ($p \leq 0.05$) with the addition of tomato pulp and red pepper pulp (Table 1; Table 2); but not changed significantly with the addition of carrot pulp (Table 3). The reduction in the expansion may be the reason of decrease in lightness (L* value). Incorporation of the carotenoids in the extrudates, with pulp addition may be the other reason. In addition, 100 g of tomatoes contains 2.8 g of sugar; 100 g of red pepper contains 5 g of sugar; 100 g of carrot contains 4.7 g of sugar which may cause browning reactions such as Maillard reaction and caramelization, since high temperature favors the browing reactions in the presence of sugars (Potter and Hotchkiss, 1995). In the studied range, sugar from the functional ingredients is very small, so browning reactions could only have a slight contribution to the reduction of lightness, with the addition of pulp.

Table 9. Color properties of the extrudates with and without carrot pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Carrot Pulp Added
L*	81.19 ± 0.33 [a]	79.60 ± 0.45 [b]
a*	2.09 ± 0.35 [a]	3.01 ± 0.17 [b]
b*	35.75 ± 1.34 [a]	39.64 ± 0.63 [b]

L*,a*,b* results are means ± SD (n= 10); values of the same row, followed by the same letter (a,b) are not statistically different ($p \leq 0.05$).

Similar results was obtained by other researchers. Altan et al. (2008a) also reported a decrease in the "L" value and an increase in the "a" value of the barley extrudates, with the addition of tomato pomace. This was attributed to the lycopene pigment in the tomatoes. Significantly increase ($p \leq 0.01$) was also reported for "b" value with increasing tomato pomace level and Altan et al. (2008a) suggested a positive correlation between "a" values and "b" values ($r = 0.992$, $p \leq 0.01$), and a negative correlation between "L"values and "b" values ($r = -0.974$, $p \leq 0.01$).

Similarly, in the study of Altan et al. (2008b), increasing grape pomace level was resulted in a decrease in "L". Thus, significant negative linear correlation between grape pomace level and "L" value ($p \leq 0.05$) was suggested. This was attributed to the browning reactions such as Maillard reaction and caramelization. Increasing grape pomace may resulted with contribution of more sugar and this favors the browning reaction. Altan et al. (2008b) indicated that grape pomace level had a positive significant effect on “a” and “b” values ($p \leq 0.05$). The increase in “a” value of the extrudates explained by the Maillard reaction and destruction of heat sensitive pigments, while the increase in “b” value of the extrudates was explained by the presence of yellowish pigments in the pomace.

3.5 TEXTURE

Hardness and fracturability (brittleness) of the corn grit extrudates were determined in order to determine the textural properties of the corn grit extrudates. Hardness indicates the maximum force (peak force) required for a probe to penetrate the extrudate, whereas fracturability indicates the distance to break the extrudate.

High values of hardness and fracturability are not desirable properties for snacks (Mendonça et al., 2000; Yanniotis et al., 2007). If the hardness of the sample is high, it means the force required for a probe to penetrate the sample is high (Li et al., 2005). The shorter the distance, the less deformation of the product encounter before cracking. In such a case, the fracturability is low and the sample is said to be brittle (Altan et al., 2008b).

Many researchers suggested that the hardness and fracturability are related to the microstructure of the extrudates and expansion characteristics of the extrudates (Jin et al., 1995; Ding et al., 2006; Altan et al., 2009). Altan et al. (2009) indicated that the extrudates with higher sectional expansion indexes and lower bulk densities have lower hardness and breaking strength values. An increase in the breaking strength was reported as a result of increasing bran content in the study of Moore et al. (1990) and as a result of increasing fiber content in the study of Jin et al.(1995). Jin et al. (1995) suggested an inverse relation between breaking strength with the radial diameter of the extrudate (r= 0.904, $p \leq 0.001$) and explained these by product cell wall thickness. Increasing fiber result in a more compact extrudate with small air cell size and thick cell walls, thus, a higher breaking strength.

Ilo et al. (1999) reported that the amaranth content was important in determining the breaking strength of rice flour extrudates. For lower amaranth levels, decreased texture in rice flour extrudates was reported while there was an increase in texture of rice flour extrudates, with increasing amaranth content. Mendonça et al. (2000) suggested a correlation between fracturability and hardness, and specific volume of extrudates (r=0.70). Yanniotis et al. (2007) reported that incorporation of the fibers and increasing the fiber content (0%, 5% and 10%) resulted in a statistically significant increase in hardness ($p \leq 0.05$). This was explained by the decrease in porosity with the addition of fiber since fiber causes thicker cell walls.

In the study of Altan et al. (2008a), results showed that a decrease in die temperature with increasing level of tomato pomace increased the product hardness and this was associated with the density which was also increased. Altan et al. (2008b) reported an increase in peak force with increasing grape pomace. Based on the studies of Lue et al. (1991) and Yanniotis et al. (2007), this was explained by the possibility of the presence of fibers. By causing premature rupture of bubbles, fiber reduces the cell size and results in the reduction of the overall expansion and less porous structure. It was also reported that increasing tomato pomace level decreased the brittleness of the barley extrudates. Altan et al. (2009) suggested a positive correlation between hardness and bulk density (r=0.725, $p \leq 0.05$); hardness and breaking strength (r=0.865, $p \leq 0.05$); breaking strength and bulk density (r=0.580, $p \leq 0.05$) while there was a negative correlation between hardness and SEI (r=0.470, $p \leq 0.05$).

3.5.1 Tomato Pulp

The maximum peak force (hardness) was determined as 10.29 ± 1.44 N and 10.06 ± 1.48 N; the distance to crack was determined as 36.56 ± 0.48 mm and 37.36 ± 0.59 mm for the corn grit extrudates, with and without tomato pulp, respectively (Table 10). Neither hardness, nor fracturability showed a statistically significant difference ($p \leq 0.05$) with the addition of tomato pulp. This could be because of the fact that fiber contribution of the tomato pulp in the studied range was low.

Table 10. Textural properties of extrudates with and without tomato pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Tomato Pulp Added
Hardness (N)	10.06 ± 1.48 [a]	10.29 ± 1.44 [a]
Fracturability (mm)	37.26 ± 0.59 [a]	36.56 ± 0.48 [a]

Results are means ± SD (n= 25); values of the same row, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

3.5.2 Red Pepper Pulp

The maximum peak force (hardness) was determined as 10.77 ± 1.35 N and 9.83 ± 1.19 N; the distance to crack was determined as 36.95 ± 0.66 mm and 37.26 ± 0.52 mm for the corn grit extrudates, with and without red pepper pulp, respectively (Table 11). Textural properties are related with the expansion characteristics of the extrudates. However, although there was a statistically significant decrease in porosity and statistically significant increase in bulk density of the extrudates with the addition of red pepper pulp, no statistically significant difference was observed in hardness and fracturability of the extrudates.

Table 11. Textural properties of extrudates with and without red pepper pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Red Pepper Pulp Added**
Hardness (N)	9.83 ± 1.19 [a]	10.77 ± 1.35 [a]
Fracturability (mm)	37.26 ± 0.52 [a]	36.95 ± 0.66 [a]

Results are means ± SD (n= 25); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.5.3 Carrot Pulp

The maximum peak force (hardness) was determined as 10.40 ± 1.68 N and 10.55 ± 1.74 N; the distance to crack was determined as 37.87 ± 0.77 mm and 37.49 ± 0.76 mm for the corn grit extrudates, with and without carrot pulp, respectively (Table 12). Having no differences in sectional expansion index, porosity and bulk density, could be the reasons of having no difference in hardness and fracturability, with the addition of carrot pulp. Fiber concentration in the carrot pulp may be not enough to make changes in the expansion characterics of the extrudates, thus textural properties of the extrudates.

Table 12. Textural properties of extrudates with and without carrot pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Carrot Pulp Added
Hardness (N)	10.55 ± 1.74 [a]	10.40 ± 1.68 [a]
Fracturability (mm)	37.49 ± 0.76 [a]	37.87 ± 0.77 [a]

Results are means ± SD (n= 25); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.6 SENSORY

When the preferences of the panelists was considered, no significant difference was observed for apperance, color, taste, hardness, crispiness, porosity and general preferences for the extrudates with and without any pulp (tomato, red pepper and carrot) (Table 13; Table 14; Table 15).

Appearance, texture and flavor are the quality factors that are determinative on the acceptibility of the products (Potter and Hotchkiss, 1995). They can be measured by using instruments, however, acceptability is highly subjective subject since we respond to the products in terms of sensory, emotional, intellectual images and expectations (Hutchings et al., 2012). Hutchings (1999) also indicated that not only the receptor mechanisms effect the acceptability of the food but also inherited and learned responses to specific events and immediate environment does matter on the motivation of buying something. Inherited and learned responces depends on the culture, fashion, physiology, preference, psychology and memory, whereas immediate environment would be affected from geographical factors, social factos and medical factors.

3.6.1 Tomato Pulp

Table 13. Sensory evaluation scores of extrudates with and without tomato pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	Tomato Pulp Added
Appearance	7.56 ± 1.13 [a]	7.22 ± 1.30 [a]
Color	7.00 ± 1.12 [a]	7.00 ± 1.58 [a]
Taste	7.11 ± 1.62 [a]	6.78 ± 1.30 [a]
Hardness	7.67 ± 1.66 [a]	7.33 ± 1.50 [a]
Crispiness	7.89 ± 1.17 [a]	7.22 ± 1.09 [a]
Porosity	7.56 ± 0.88 [a]	7.33 ± 0.71 [a]
General Preferences	7.78 ± 1.09 [a]	7.33 ± 1.12 [a]

Results are means ± SD (n= 9); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.6.2 Red Pepper Pulp

Table 14. Sensory evaluation scores of extrudates with and without red pepper pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Red Pepper Pulp Added**
Appearance	7.22 ± 1.09 [a]	7.00 ± 1.32 [a]
Color	7.22 ± 1.10 [a]	7.67 ± 1.50 [a]
Taste	6.67 ± 1.80 [a]	6.67 ± 1.58 [a]
Hardness	6.78 ± 2.28 [a]	7.00 ± 1.58 [a]
Crispiness	7.33 ± 1.58 [a]	7.00 ± 0.87 [a]
Porosity	7.11 ± 1.05 [a]	7.00 ± 0.50 [a]
General Preferences	6.78 ± 1.72 [a]	7.00 ± 1.00 [a]

Results are means ± SD (n= 9); values of the same row, followed by the same letter (a) are not statistically different (p≤0.05).

3.6.3 Carrot Pulp

Table 15. Sensory evaluation scores of extrudates with and without carrot pulp (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min.

	Corn Grit	**Carrot Pulp Added**
Appearance	6.89 ± 1.05 [a]	6.89 ± 0.60 [a]
Color	6.67 ± 0.87 [a]	7.22 ± 1.09 [a]
Taste	6.11 ± 1.54 [a]	6.56 ± 1.42 [a]
Hardness	7.33 ± 0.71 [a]	7.11 ± 0.93 [a]
Crispiness	7.33 ± 0.71 [a]	6.78 ± 0.68 [a]
Porosity	7.00 ± 0.87 [a]	6.56 ± 0.73 [a]
General Preferences	6.56 ± 0.88 [a]	6.44 ± 1.01 [a]

Results are means ± SD (n= 9); values of the same row, followed by the same letter (a) are not statistically different ($p \leq 0.05$).

Based on the result of the sensory analysis, tomato pulp, red pepper pulp and carrot pulp can be successfully added as a functional ingredient to the extruded products without affecting the acceptability of the consumers.

3.7 DIETARY FIBER ANALYSIS

Dietary fiber is a term used to define the heterogenous mixture of plant food components that are indigestible in the small intestine (Dreher, 2001). The composition of dietary fiber, which is found only in foods of plant origin such as whole grains, legumes, nuts, seeds, fruits and vegetables, varies with the type of plant tissue and the proportions depend on the maturity of the plants as well as storage and ripening (Dreher, 2001; Gelroth and Ranhotra, 2001). Processing of foods may also alter the native composition of fiber (Dreher, 2001).

The term dietary fiber is viewed as total dietary fiber and includes both water insoluble dietary fiber and water soluble dietary fiber (Dreher, 2001; Gelroth and Ranhotra, 2001). Insoluble dietary fiber, which constitutes 75% of the total dietary fiber in a food, consists mainly of cell wall components such as cellulose, lignin and hemicellulose, whereas soluble dietary fiber consists of noncellulosic polysaccharides such as pectin, gums, and mucilages (Dreher, 2001).

Soluble and insoluble fiber content analysis were conducted to determine the fiber contents of the ingredients used in the study. Results were shown in Table 16.

Table 16. Fiber content of the corn grits, tomato, red pepper and carrot.

Samples	Corn Grits	Tomato Pulp	Red Pepper Pulp	Carrot Pulp
Moisture Content (%)	12.19 ± 0.06	93.97 ± 0.18	91.19 ± 0.22	88.22 ± 0.12
Insoluble DF (g/100g wet basis)	8.10 ± 0.86	0.98 ± 0.15	0.87 ± 0.24	0.60 ± 0.18
Soluble DF (g/100g wet basis)	2.02 ± 0.84	0.35 ± 0.12	0.51 ± 0.28	0.89 ± 0.12
Total DF (g/100g wet basis)	10.12 ± 0.70	1.33 ± 0.15	1.38 ± 0.28	1.49 ± 0.18

Results are means ± SD (n= 2).

CHAPTER 4

CONCLUSION

In summary, effects of tomato pulp, red pepper pulp and carrot pulp addition on the quality parameters of the corn grit extrudates were investigated. The results showed that tomato pulp addition decreased sectional expansion index, however, the data indicated no statistically significant difference on longitudinal expansion index, volume expansion index, bulk density and porosity values when expansion characteristics were considered. Red pepper pulp addition decreased longitudinal expansion index, volume expansion index and porosity values of the corn grit extrudates, while increasing the bulk density, however, no statistically significant difference was observed in sectional expansion index. Carrot pulp addition had no significant effect on any of the expansion characteristics. Considering color of the extrudates, lightness of the extrudates was decreased, redness and yellowness of the extrudates were increased, as a result of pulp addition (tomato, red pepper and carrot). Water absorption and water solubility indexes of the extrudates were not affected by the pulp addition (tomato, red pepper and carrot). Considering the textural properties of the extrudates, which are considered as the most important characteristics of the extruded snacks, determining the acceptibility of the products, no significant difference was observed in hardness and fracturability of the extrudates with pulp addition. Sensory evaluations also indicated no significant difference, when panelist preferences were considered.

Considering the health benefits of tomato, red pepper and carrot, even though having a slight decrease in expansion, it can be concluded that tomato pulp, red pepper pulp and carrot pulp can be successfully added as a functional ingredient to the extruded products.

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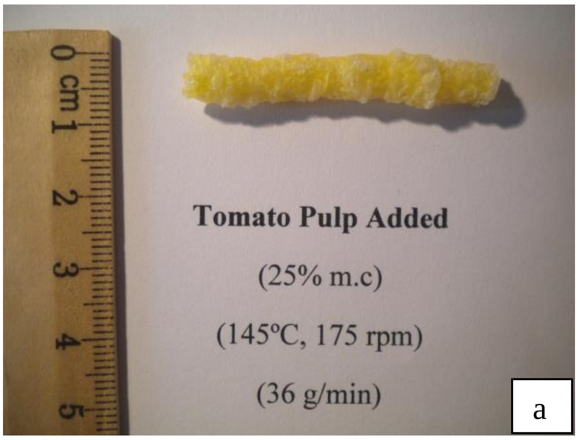
APPENDIX A

IMAGES OF THE EXTRUDATES



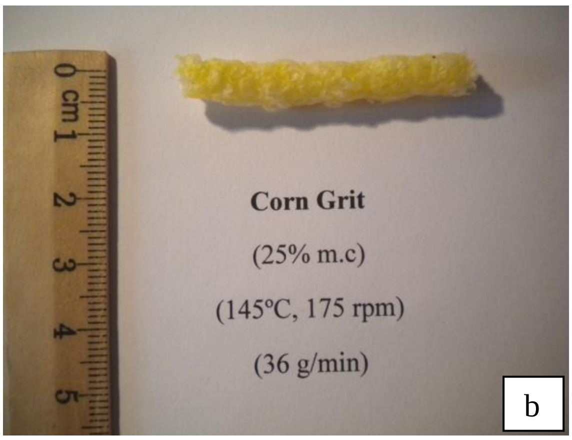
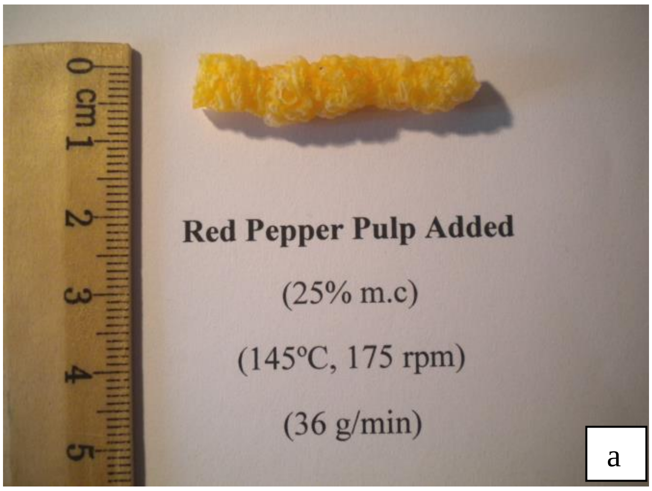


Figure 8. Images of the extrudates (%25 feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36 g/min. **a)** Tomato pulp added. **b)** Control.



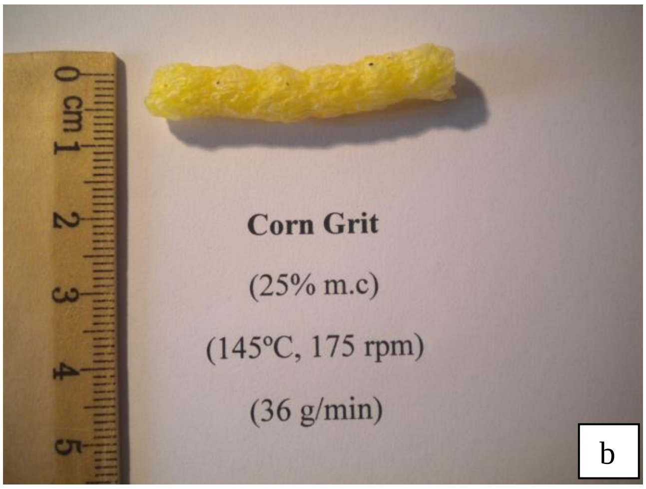
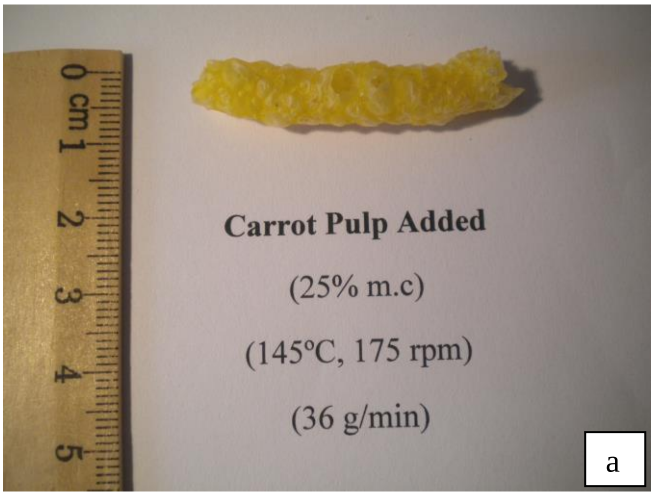


Figure 9. Images of extrudates (25% feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36g/min. **a)** Red pepper pulp added. **b)** Control.



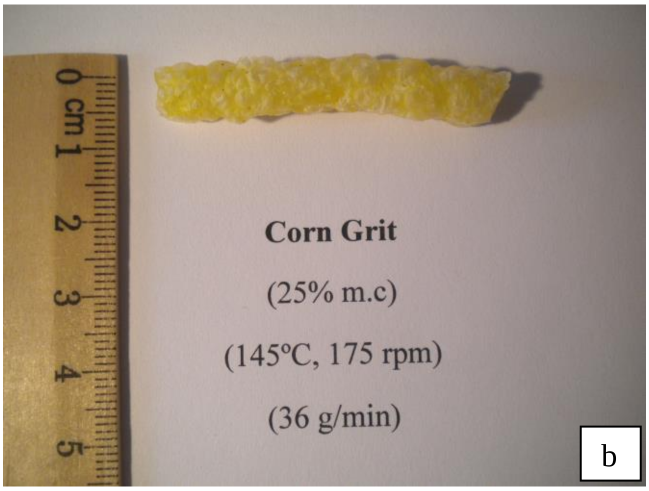


Figure 10. Images of extrudates (25% feed moisture), extruded at 145ºC last zone temperature and 175 rpm with feeding rate of 36g/min. **a)** Carrot pulp added. **b)** Control.