DEVELOPMENT OF EXPANDED SNACK FOODS CONTAINING PUMPKIN FLOUR AND CORN GRITS USING EXTRUSION TECHNOLOGY

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Abstract

The production of expanded snack foods using vegetable powder as an ingredient in ready-to-eat food is rare. In view of its natural desirable colour, flavour, sweetness and health benefits, pumpkin was chosen as an additive to the traditional corn grits or rice used as the basis of an extrusion expanded snack or breakfast food concept. Pumpkins also have a large range of uses as a potentially valuable food for humans and animals. However, they are an underutilised product. This study was undertaken to demonstrate the potential of pumpkin products as additives in expanded snack food products. Processing the fresh pumpkin into flour dramatically extends the shelf life and makes the ingredient available throughout the year. The flour is more convenient for extrusion as it is stored and handled as a dry powder. Research was conducted to produce and characterise pumpkin flour made by convection oven and freeze drying of a pumpkin fractions such as peel, pulp (rind), flesh and seed. The flour was combined with corn grits in various proportions up to a maximum of 20% w/w. After determining suitable processing conditions and the maximum acceptable concentration of pumpkin flour for an edible product, the effect of process parameters on product quality were determined. Finally the product was optimised using response surface methodology (RSM). The proximate compositions of pumpkin flour from convection oven and freeze drying were as expected identical to commercial pumpkin flour. The carbohydrate content ranged between 69.8 and 89%, protein ranged between 1.3 and 21%, and fat between 0.03 - 0.53%. Pumpkin flour produced by freeze drying revealed *L, a* and *b* values higher than in commercial pumpkin flour, indicating that the flour was lighter in colour and appeared more orange than that oven dried. The effect of varying pumpkin flour proportion at two mass flow rates of 7.5kg/hr and 8.5kg/hr revealed that mass flow rate did not have any significant correlation to the extrusion parameters and the final quality of the expanded snack product. However, a high quality final product can be achieved at all mass flow rates with less than 20% pumpkin flour incorporated into the blend. Varying the proportion of pumpkin flour between 5% and 20% in combination with corn grits using screw speeds of 250rpm and 350rpm showed that, increasing the proportion of pumpkin flour to 20% significantly ($P<0.05$) decreased specific mechanical energy (SME) and torque. The extruded pellets using a 20% blend of pumpkin with corn grits were harder, more denser and less expanded than those made with higher proportions of corn grits. The crispiness and hardness of the final product was not closely related to the number or area of bubbles present in the structure. Screw speed did not significantly ($P>0.05$) affect the specific mechanical energy (SME)

or the physical characteristics of the final product. Hardness seemed to be due to bubble wall stiffness i.e. effectively the thickness and rigidity of the set starchy matrix. Response surface methodology (RSM) was predicted four solutions for optimum conditions which can be achieved at barrel temperature ranging from 165°C to 167°C at a constant feed rate of 10.50kg/hr and pumpkin flour percentage ranged from 16% to 17%. With these conditions, the optimum SME of 0.15 was achieved and this product had a maximum radial expansion of 11.00%, hardness less than 142.0N with a total carotenoid content of 2.07ppm to 2.13ppm. Sensory analysis revealed most consumers preferred expanded snack products containing 5% pumpkin flour and produced by extruding at a barrel temperature of 170°C and mass flow rate of 12.0kg/hr. The panellists indicated that they would buy this product due to its acceptable taste, texture, odour and overall product characteristics. However, the expanded snack with 15% pumpkin flour was found to have highest total carotenoid content (5.78ppm) and protein content (28.8%) after processing and may have been, in nutritional terms, the best product. The slowly digestible starch (SDS) value and carbohydrate content of this product was found at 97.03mg/g and 59.29% respectively. From this work useful information regarding pumpkin flour and its application in extruded expanded snack production was obtained. This work has the potential to diversify the application of pumpkin flour and offer new uses for pumpkin in the food industry.

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Norfezah Md Nor
Autumn 2013

In Memory

Aminah Hashim (mom)

Nurul Izzah Jaafar (daughter)

Som Mat (grandma)

Omar Osman (father in law)

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Journal Articles

Norfezah,M.N., Carr, A., Hardacre, A., & Brennan, C.S. (2013). The development of expanded snack product made from pumpkin flour- corn grits : Effect of extrusion conditions and formulations on physical characteristics and microstructure. *Foods* (Accepted 3rd May 2013).

Norfezah, M., Hardacre, A., & Brennan, C. (2011). Comparison of waste pumpkin material and its potential use in extruded snack foods. *Food Science and Technology International, 17*(4), 367-373.

Conference Proceedings

Norfezah, M.N., Hardacre,A., Carr, A., & Brennan, C.S. Effect of varying pumpkin flour and screw speed on the extrusion parameters, physical characteristics and microstructure of the development added-value expanded snack products. In *The Proceeding of 44th Annual AIFST Convention "Tackling Tomorrow Today", 10-13 July 2011, Sydney Convention Centre, Darling Harbour, Sydney, Australia.*

Norfezah M.N.,Hardacre A.K., Carr A.J., Brennan C.S. The effect of process parameters on the operating conditions and physical properties of extruded breakfast cereals made from pumpkin flour and corn grits. In *The Proceedings of New Zealand Institute of Food Science (NZIFST) Conference : Food Elements-Putting The Pieces Together, 23rd-25th June 2009, Christchurch Convention Centre, Christchurch, New Zealand.*

Norfezah, M. N., Brennan, C.S.& Hardacre, A. Utilization of pumpkin flour in expanded breakfast cereals. In *Total Food Proceeding : Sustainability of the Agri-Food Chain International Conference, K.W.Waldron, G.K.Moates, C.B. Faulds (eds), 22-24 April 2009, Norwich, UK*, pp105-108

Oral presentation

Norfezah,M.N. (2009). Optimization of process parameters for production of extruded snack food made from pumpkin flour and corn grits. (Oral presented at IFNHH Seminar on 19/8/09)

Chapter 1: Introduction

This chapter introduces the purpose of the study. An overview of each chapter in this thesis is provided.

1.1 Background of the Study

This research was conducted to investigate the potential of processing the whole pumpkin fractions including peel, pulp (rind), flesh and seed into a usable flour for extrusion processing, particularly for the manufacturer of the expanded snacks.

Pumpkin is a widely consumed food either directly as a vegetable or as a thickener and flavour base in soups, sauces and spice mixes. Moreover, pumpkin can also provide a natural yellow-orange colouring agent when blended with cereal flour, pasta and extrusion expanded snacks. Pumpkin flour contains 350-400ug/100g β carotene which is converted to vitamin A in the body along with pectin (14-22%), dietary fibre (0.5g/100g) and minerals. It also gives natural sweetness to the product due to high levels (37%) of sugar in the flesh. In view of its nutritional value and flavour characteristics, pumpkin flour is a potential ingredient for producing expanded snacks.

In Malaysia, the utilisation of pumpkin has been limited to the consumption of fresh products as a vegetable and alternately grown after tobacco plant. In line with the Malaysian government's effort to redevelop and reposition the Agriculture Industry – "Agriculture is Business", this study may provide useful information about pumpkin flour and its application in food production. Diversifying the usage and processing of pumpkin, it could increase the returns for pumpkin growers in Malaysia. In contrast, processing pumpkin for powder in New Zealand resulted in more than 25% of the fruit being wasted as only the fleshy part was used. Reducing the waste by using seed, peel and pulp (rind) may offer one of the best routes to increasing the productivity of this industry.

There is a large range of snack foods on the supermarket shelves with a large variety of sizes, shapes, colours and flavours available. The snack food market is expanding rapidly and growth is forecast to continue into the future. The worldwide market for snack food is expected to rise to USD$334 billion with a production volume of 48.5 million metric tonne by 2015 (Euromonitor, 2010). Potato chips followed by corn chips dominated the snack food market throughout the world. Most snacks are made from cereal grain (e.g. corn, wheat, rice and oats) which are usually low in nutritional components such as vitamins and amino acids. Over the past ten years consumers have become more health conscious and are choosing snacks that claim to be healthier and more nutritious. Therefore snack foods that are low fat, fibre-rich, vitamin and mineral fortified and have organic claims have become more popular and in high demand. However, the production of healthier snack food is not only limited to natural seasoning and flavour but could be achieved by incorporating fruit and vegetable products into the formulation (Sacks et al.,1999; Block, Patterson & Subar ., 1992). Only a few researchers have investigated the potential used of fruit and vegetables in snack food production. Ibanoglu, Ainsworth, Ozer and Plunkett.,(2006) made a gluten free snack, a rice flour-acorn squash blend extruded snack is described by Morini and Maga, (1995) and a barley-tomato pomace blends by Altan, McCarthy and Maskan.,(2008). Incorporation of pumpkin powder with whole cornmeal in the extrusion process has been done by Karkle, Alavi,Dogan, Jain and Waghray (2009) while Mastromatteo,Danza, Guida and Del Nobile (2012), added pumpkin powder in bread making.

In this study, expanded snack foods made from vegetable powder will be compared with emphasis on the improved nutritional value that results from the use of pumpkin flour.

Based on preliminary work that has been done in this study, extrusion technology can be used to make tasty, nutritious snacks or breakfast cereals from pumpkin flour when blended with corn-grits. However, the main constraint in producing extruded products containing high levels of pumpkin flour is the high level of sugar (37%) in the flour that reduces expansion and makes an unacceptably hard product (J.F. Faller, J.Y.Faller & Klein., 2000). Therefore, it is a challenge to determine the optimum process parameters needed to obtain the desired product characteristics, which include acceptable expansion and product density. In this study the feasibility, suitability, and acceptability of pumpkin flour as an ingredient in food extrusion will be examined.

1.2 Purpose of The Study

The overall objectives of this research is to determine the feasibility of using pumpkin flour as an ingredient for the manufacture of extrusion cooked expanded snack foods.

1.3 Significance and Rationale of Study

The products are expected to have improved nutritional properties compared with tradition cereal based snacks. Demonstration of an acceptable product will also provide new opportunities for the snack food industry while increasing the market for pumpkin products.

1.4 Research Aims and Objectives

In line with the background of the study the proposed study attempts to answer the following research questions:

1. How to enhance and diversify the usage of pumpkin?
   Can it be processed into a food ingredient or flour?

2. What are the possible applications of pumpkin flour?
   Is it suitable as an ingredient in the manufacture of snacks?
   Do pumpkin-enriched snacks have a high nutritional value?
   What is the level of consumer acceptance of pumpkin enriched snacks?

3. Extrusion

   What are the best parameters (operating conditions) of the Clextral BC21 Twin Screw Extruder for extruding pumpkin enriched snacks food?

   What is the highest concentration of pumpkin flour (edible fractions: flesh and seed) that can be used for the extrusion of expanded snacks?

   What types of cereal (for example: corn grits) can be used to enhance the organoleptic properties of extruded pellets made with pumpkin flour?

   What is the most suitable level for each of the cereal grits?

4. To determine digestibility (Glycaemic Glucose Equivalent) of the starch component in the extruded pumpkin enriched snack foods.

1.5 Overview Outline

This thesis comprises eight (8) chapters:

Chapter 1 provides the background of the study, the purpose of the study and potential contributions of the study for pumpkin growers, snack food manufacturers and consumers. An overview of the thesis structure is also provided.

Chapter 2 is a review of current and past issues related to the extrusion of snack foods, and to the use of pumpkin and corn grits.

Chapter 3 describes the characterisation of pumpkin and pumpkin flour production. This preliminary work will be focused on exploring and processing of fresh pumpkin into flour. Two types of pumpkin (Crown and Buttercup) with two drying methods which are convection oven and freeze drying. The flours produced in this work will also be compared with commercial pumpkin flour produced by Cedenco.

Chapter 4 reports the results from the preliminary extrusion processing of snacks made from a blend of pumpkin flour and corn grits. This work covers a wide range and looks at many different factors which preliminary experiments and literature suggest might have an effect.

Chapter 5 reports the effect of varying the proportion of pumpkin flour at two extruder feed flow rates and at two screw speeds on the processing parameters and the physical characteristics of the expanded snack This trial was carried out in order to establish the conditions that can be used to process snacks containing high levels of pumpkin flour. Correlation between the parameters also has been studied.

Chapter 6 describes the product optimisation process, in terms of the optimum formulation and extrusion conditions for production of pumpkin rich snacks including corn grits. Response surface methodology with a central composite design was used. Three independent variables were selected which were temperature (°C), feed rate (kg/hr) and pumpkin flour percentage (%).

Chapter 7 assesses the final product quality based on total carotenoid content, starch digestibility and microstructure of the product. Total carotenoid was analysed to determine the retention and stability of total carotenoid content during extrusion processing. Losses and the stability of the total carotenoid in the final product were measured and compared with levels in the unprocessed ingredients. Starch digestibility was determined to assess the effect of processing conditions on starch digestibility. This is linked to the blood sugar levels of consumers. The microstructure was studied in order to understand the role of bubble formation in the structure of the extrudate products, which reflects on the final product quality. Sensory evaluation determined the acceptance and preference of these extruded products by consumers. These results were linked to the physical characteristics of the product and the processing conditions.

In the final chapter, the summary, conclusion and recommendations of the whole study will be given.

1.6 Thesis Outline

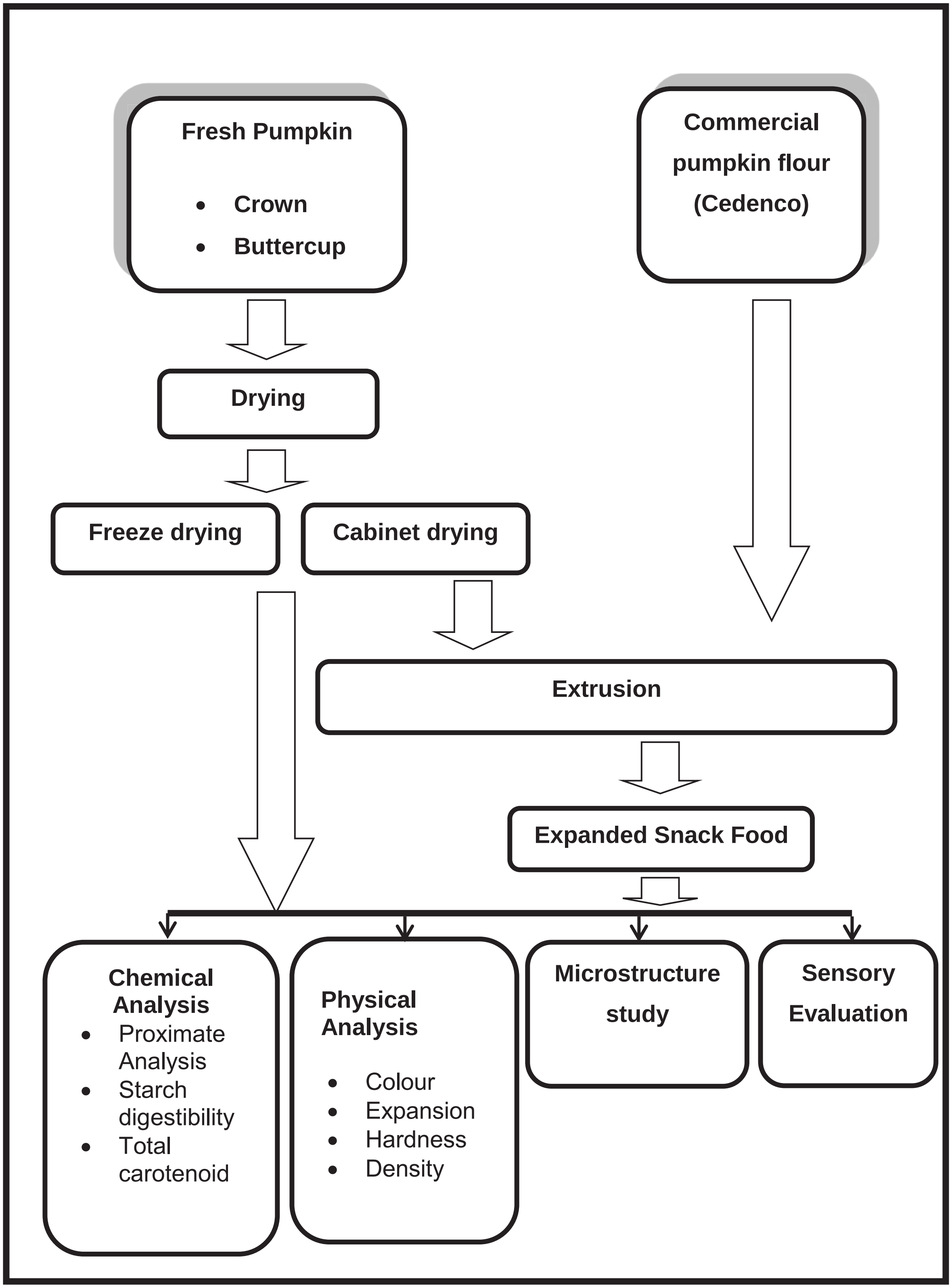


Figure 1-1: An overview of thesis outline

Chapter 2: Literature Review

This chapter is a review of current and past issues regarding the development and trends of snack foods and extrusion technology. Previous work on pumpkin utilisation and research is also reviewed.

2.1 Introduction

Malaysia's food and beverage processing industry comprises more than 3,200 businesses with a total output in excess of US$ 13 billion (Borris, 2002). Therefore, food and beverage manufacturing provides the biggest value of gross output compared to other industries. Moreover, research has found that the main contributors to the growth of the Malaysian economy are the services, manufacturing, and agriculture sectors (Hun, 2012). Most food processing in Malaysia operates within the agro-based industry.

Malaysia produced 874,602 metric tonnes of vegetables in 2011 (Crop Statistic Information, 2013). Most commercial-based food processing is agro-based, due to Malaysia's major contribution to health and well-being. However, the growth of per capita consumption of vegetables has not been as high as those meats and fish food products.

As snack food consumption is increasing due to a number of global trends and changing lifestyles (Kruger, 2012), along with demand for healthy snack option , adding pumpkin powder in the extruded snack food may give a new prospective and alternative for healthy extruded snack food production. Most snack foods contain a high proportion of corn, wheat and rice, with potato and oat and other grain products commonly added in smaller quantities. Vegetable powders are occasionally added but are not common in ready-to eat (RTE) snacks.

Pumpkin is a good source of carotenes which are responsible for the yellow colour of the flesh, they also contain appreciable levels of sugar and pectin. Sugar sweetens products that include pumpkin, while pectin is a soluble fibre that delivers many health benefits. However, the utilisation of pumpkin has been limited to the consumption of fresh products as a vegetable, or thickeners in soups and purees (Konopacka., et al., 2010) and the production of dry powders (flours) that are also used to colour, flavour and thicken a range of foods. A potential avenue of development for pumpkin based products is in the expanded snack market where pumpkin can be used to naturally enhance the flavour and colour of these products.

In line with the Malaysian Government's effort to redevelop and reposition the Agriculture Industry – "Agriculture is Business" this study may provide useful information about pumpkin flour and its application in food production. Furthermore, there are some agricultural sector activities that are no longer viable such as planting tobacco (Abdullah, 2006). Pumpkin is a suitable crop to replace the tobacco crop, since pumpkin is often planted alternately with tobacco.

Research on utilisation and feasibility of using fruit and vegetable powder, paste, and juice or extrusion to produce extruded snack has been reported for 30 years (Maga & Kim, 1989). A summary of current research on fruit and vegetable powder inclusion in extruded snack is shown below:

Table 2-1 : Summary of current research on vegetable and fruit inclusion during extrusion processing

Research	References
Lycopene extraction from extruded products containing tomato skin	Dehghan-Shoar,Z,Hardacre,A.K., Meerdink,G & Brennan,C.S. (2011)
Effect of extrusion cooking on functional properties and in vitro starch digestibility of barley- based extrudates from fruits and vegetable by-products	Altan, A., McCarthy,K.L & Maskan, M. (2009).
Comparison of waste pumpkin material and its potential use in extruded snack foods	Norfezah,M.N., Hardacre, A.K & Brennan, C.S (2011)
Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks	Stojceska,V.,Ainsworth, P., Plunkettt, A., Ibanoglu, E.& Ibanoglu, S (2008)

2.2 Snack Foods

Snack foods have a junk food image in which they are perceived to have little or no nutritional value. The 21st century saw the revolution of snack food towards healthier snacks and snack food manufacturers started adding fruit and vegetables about 30 years ago. The exact definition of "snack food', covered by a broad range of definitions. Most of which describe snacks on the basis of size and the occasion when they are consumed (Matz, 1993; Riaz,2006).Snack foods are also defined as a light meal eaten between regular meals which include a variety of products that can take many forms such as potato chips or cereal-based snacks (Sajilata & Singhal, 2005). A snack is also defined by the American Heritage Dictionary (as cited in Riaz, 2006) as a hurried or light meal that is eaten between meals and can be considered as a reward or a treat.

Most snack foods in the market are cereal- based, usually corn, wheat, rice, potato, tapioca or oats (Riaz, 2000). A number of research snack foods made from vegetable powder have been produced as summarised in **Table 2-2** below:

Table 2-2 : Summary of research on snack food vegetable enrichment

Type of vegetable powder	Researcher
Soy	Liu et al.,(2005) Nwabueze, T. (2007)
Tomato	Dehghan-Shoar, Z., Hardacre, A. K., Meerdink, G., & Brennan, C. S. (2011). Ibanoglu, S., Ainsworth, P., Ozer, E. A., & Plunkett, A. (2006)
Yam	Alves et al., (2002)
Carrot, basil	Ibanoglu, S., Ainsworth, P., Ozer, E. A., & Plunkett, A. (2006).

The main ingredients for making snack foods are grain-based and are normally wheat flour and corn. Other ingredients include fat, oils, emulsifiers and antioxidants. However, in this study the main ingredients will be pumpkin flour and corn grits.

Snack foods are manufactured using various methods of production. In this study the only method of snack food production that will be considered is extrusion, which will be covered in **section 2.5**.

2.3 The Snack Food Market

The snack food market is increasing and snacks occur in a wide variety of shapes, flavours and colours. This section will discuss an overview of current market trends and growth of sweet and savoury snack foods in five (5) selected countries; Malaysia, New Zealand, Australia, the United Kingdom and the United States.

The increased demand for the snack food was found due to several factors:

i. Changes of life styles which more people spent time at work, less food preparation, doubled income.
ii. Highly mobile population
iii. Growth in snack vending machines and convenience markets

According to the Euromonitor International report (2010), the retail value of snack food particularly sweet and savoury snacks, increased by 4% in the year 2009 compared to 2008. This is shown in **Figure 2-1.**

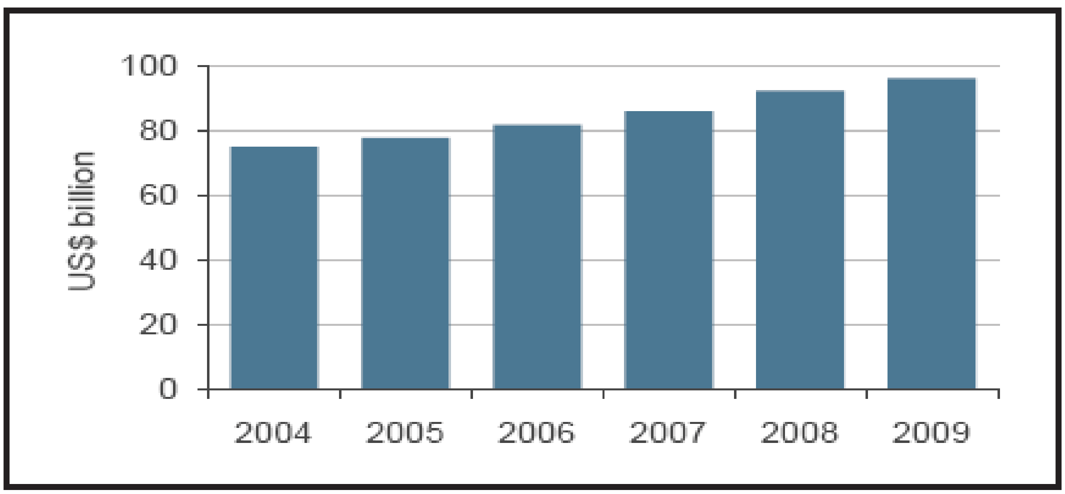


Figure 2-1 : Global sweet and savoury snacks retail value sales 2004-2009

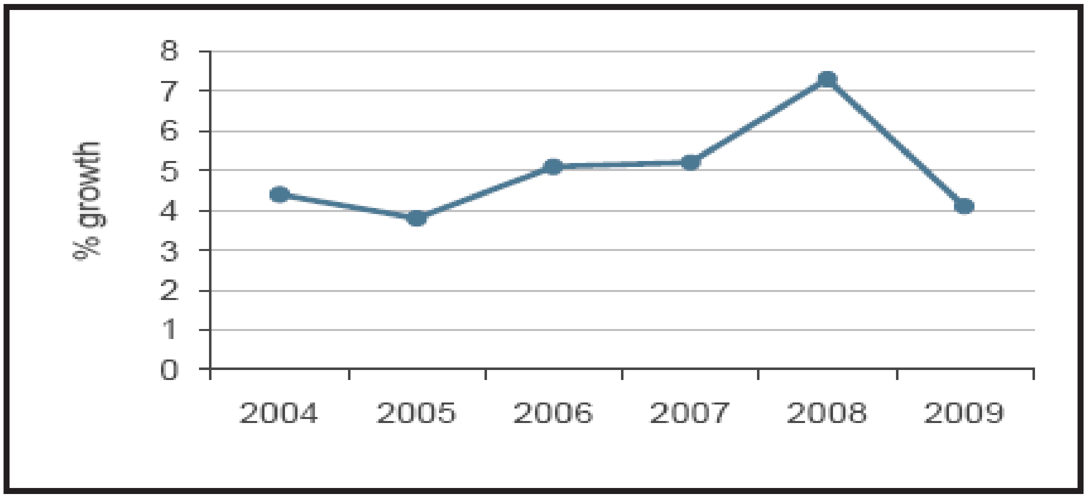


Figure 2-2 : Global sweet and savoury retail value sales 2004-2009

However, the global retail volume was found to be slowing down by the year 2009 compared to 2008 (as shown in **Figure 2-2)** this was due to an economic downturn and health conscious consumers moving towards healthy snacking. This offered a new opportunity to the food industry in exploring, developing and innovating healthier snack food products.

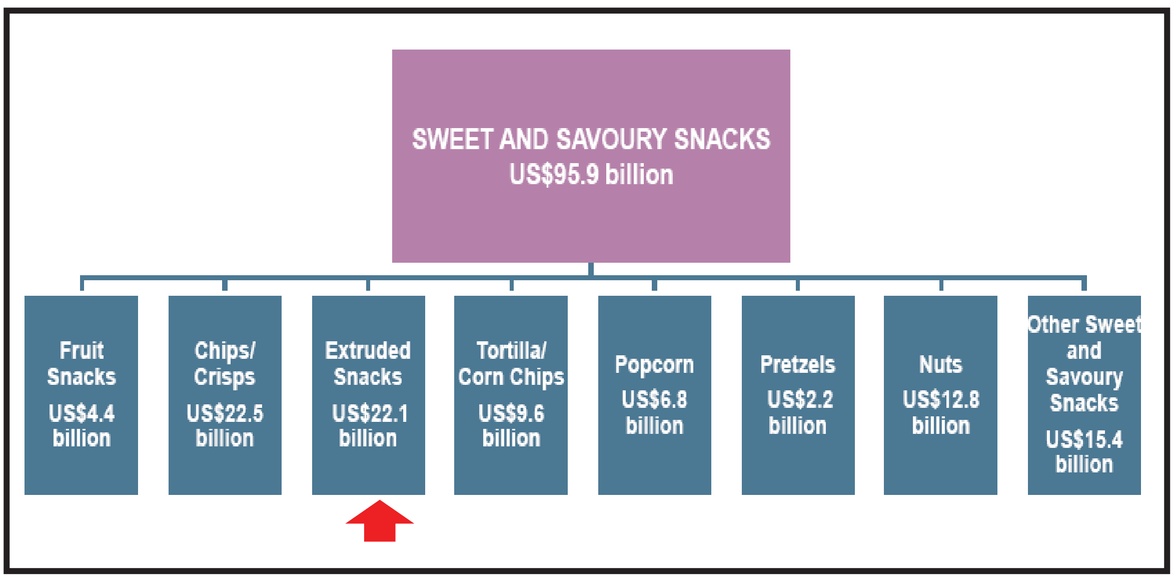


Figure 2-3 : Global sweet and savoury retail value growth 2004-2009

Based on product type (**Figure 2-3**), chips dominated the sweet and savoury snack market, closely followed by extruded snacks. This is shown by the red arrow marker.

2.3.1 Sweet and Savoury Snacks Market in Malaysia

Snacking is a part of Malaysian culture and the sweet and savoury snacks market in Malaysia was worth US$34.0 million (RM105.7 million) in 2010. Extruded snacks and popcorn dominated the snack market. However, the traditional snacks such as muruku, green peas, fruit jellies and cuttlefish remained popular among Malaysians.

2.3.2 Sweet and Savoury Snacks Market in New Zealand

The value of sales of sweet and savoury snacks in New Zealand reached US$287.04 million (NZ$349 million) in 2010 representing an impressive growth of 3% over 2009. Health-related trends towards healthy snack products which include high fibre, whole grains, and less trans fats and fats continued to grow well. Popcorn was the largest growth sector with 48% volume growth, followed by nuts (42.2%) and extruded snacks (22.6%).

2.3.3 Sweet and Savoury Snacks Market in Australia

According to the Euromonitor International report (2010), nuts dominated the sales of sweet and savoury snacks approximately 38.26% of the market, followed by extruded snacks (26.76%). This was due to health conscious parents directing the healthy snacking habits of their children. Overall the sweet and savoury market was found to be worth more than US$615.66 million (A$605.52 million) in 2010. The extruded snack market increased by 26% from the year 2005 to 2010 (Euromonitor International, 2010).

2.3.4 Sweet and Savoury Snacks Market in the United Kingdom

Throughout the European market, the United Kingdom contributed the largest sales of snack foods with approximately US$1,410.11 million (£938.2 million) in sales of extruded snacks. Overall, there was an increment of 4% in sales of the sweet and savoury snacks over the years 2005 to 2010. The report showed healthy snacking was driven by the dynamic growth of tortilla chips (13%) and popcorn (7%) sales in the year 2010.(Euromonitor International, 2010).

2.3.5 Sweet and Savoury Snacks Market in the United States

The sweet and savoury snacks market in the United States by the year 2010, saw retail volume fall slightly across the product categories with the exception of nuts. Overall, the value of snack sales was US$32 billion in 2010 with chips dominating the supermarket shelves (35.6%) followed by nuts (30.0%), fruit snacks (29.3%) and extruded snacks (20.8%). The sales of sweet and savoury snacks were predicted to grow 3% in volume terms over the years 2010 to 2015 (Euromonitor International, 2010).

2.4 Extruded Food Products

Extruded snack foods or expanded snacks have been identified as one of the fastest growing snack segments and have great potential to be explored. Expanded corn snacks were among the first extruded snacks to be introduced and commercialised in mid to late 1940s. Presently, a variety of shapes, colours and flavours of extruded snacks are available in supermarket, grocery retailers, corner stores, gas stations, vending machines, cinemas as well as at sports events or theme parks. **Table 2-3** shows examples of some extruded snack food products.

Table 2-3 : Examples of extruded food products produced by extrusion

Category	Extruded Food
Ready to eat breakfast cereal	Puffed and flaked cereals High fibre strands
Snacks	Puffed snacks and crisp breads Half-products or pellets (third generation snack)
Confections	Liquorice and chocolates
Texturised protein	Soy meat analogues Restructured seafood Processed cheese
Infant foods	Biscuits Weaning cereals

Extrusion processing is a key technology in snack food production, however, it can also be applied to a variety processed foods such as breakfast cereals, baby foods, meat, cheese analogues and modified starches (as cited in Ding, Ainsworth, Tucker & Marson, 2005).

2.5 Extrusion

2.5.1 Introduction

Extrusion is a versatile and very efficient technology that is widely used in food and feed processing. Extruders have been used for many applications, which include: breakfast cereals, snack foods, other cereal - based products, pet food and aquatic foods, texturised vegetable proteins, confectionery products, chemical and biochemical reactions, and oil extraction. It is a device that expedites the shaping and restructuring process for food ingredients which can be applied to a variety of food processes (Riaz, 2000). Extrusion processing involves some of these functions: mixing, homogenisation, shearing, thermal cooking and shaping. The main reasons that extrusion is used are:

- Versatility – A wide range of products can be produced ; dry and semi-moist pet foods, expanded snacks, breakfast cereals, pastas, infant foods, confectionary, textured vegetable protein (TVP) and flavoured compounds
- Reduced production costs - factors such as higher throughputs, less labour, reduced energy input, reduced wastage and reduce effluents
- The ability to produce products with specific properties and based on consumer demand. This can be achieved through controlling the ingredients and the operating conditions.

2.5.2 Definitions of Extrusion

Extrusion is defined as a process that transforms a granular raw material into a continuous plasticised mass through a high-temperature-short-time (HTST) process. The end product, known as an extrudate is a highly expanded, porous solid, obtained from the dissipation of mechanical energy in the extruder and the sudden pressure drop as the material is forced through the die.

Rossen and Miller (1973) defined food extrusion as a process in which a food material is forced to flow, under one or more varieties of conditions of mixing, heating and shear, through a die which is designed to form and/or puff-dry the ingredients.

2.5.3 Background and Development of Extruder

Extrusion has been widely used in the manufacturing industry during the past two centuries. A brief history of the development of extrusion is outlined in **Table 2-4** below.

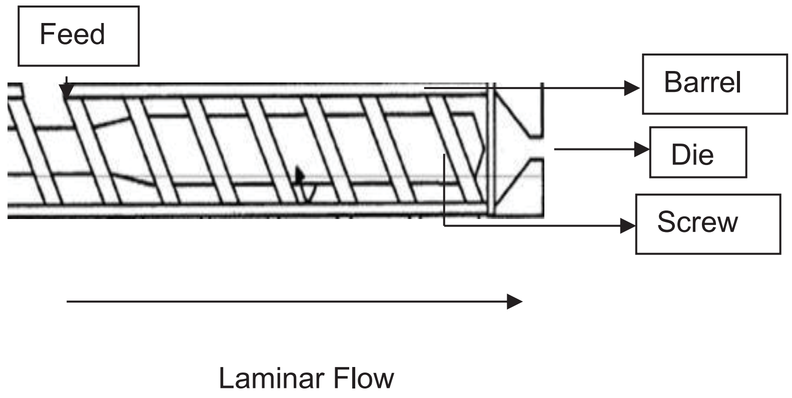
Table 2-4 : Brief history of extrusion development (Riaz, 2000)

Year	Brief History of Extrusion
1797	Development of a hand-operated piston press to extrude seamless lead pipe by Joseph Bramah, England.
1869	First continuous twin screw extruder was developed in sausage manufacture by Fellows & Bates, England.
1873	First Single Screw Extruder was developed in rubber processing by Phoenix Gummiwerke , A.G., Germany
Mid 1930's	Single-screw continuous pasta press was developed
Late 1930's	Twin screw extruder for making plastic was developed
Late 1930's	First single screw extruder used for ready-to-eat breakfast cereals (prior to flaking)
1939	Expanded corn curls or "collets" were first extruded
1940's	Single screw oil presses was developed replacing the hydraulic presses
Late 1940's	Cooking extruder for manufacturing animal feed was developed
1950	Dry expanded pet food - Pre cooked flours
Late 1950's	Development of pressurised pre-conditioner
1960's	Ready-to-eat (RTE) & Textured Vegetable protein were produced by extruders
Mid 1970's	Second generation of extruder was developed (segmented screw & barrel)
Early 1990's	Third generation of extruder was developed (Conditioners & vented barrels)
Late 1990's (1998)	New generation extruders were patented by Wenger Manufacturing Co. (Sabetha, KS)

2.5.4 Types of Extruder

Extruders used in food applications are usually single-screw extruder or twin-screw extruder and both are generally classified based on the number of screws. **Figure 2-4** showed a schematic diagram of single and twin screw in extruder below.

1. Single screw extruders



2. Twin screw extruder

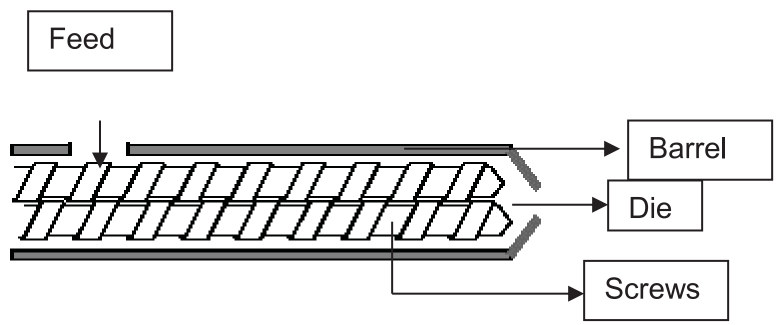


Figure 2-4 : Single screw extruder and Twin screw extruder

2.5.4.1 Single-Screw Extruder

Basically, this type of extruder is a relatively simple, reliable and extremely effective means of cooking and forming wide variety of products. A schematic diagram of a single model extruder is shown in **Figure 2-5.** A single screw extruder can be classified based on several different characteristics such as:

i. Wet vs dry
ii. Segmented vs solid screw
iii. Shear : cold forming extruder, high-pressure forming extruder, low-shear cooking extruder, collet extruder, high shear cooking extruder
iv. Heat generated : adiabatic, isothermal extruder, polytropic extruder
v. Based on its design : solid single-screw extruder, interrupted-flight extruder-expander, single segmented-screw extruder

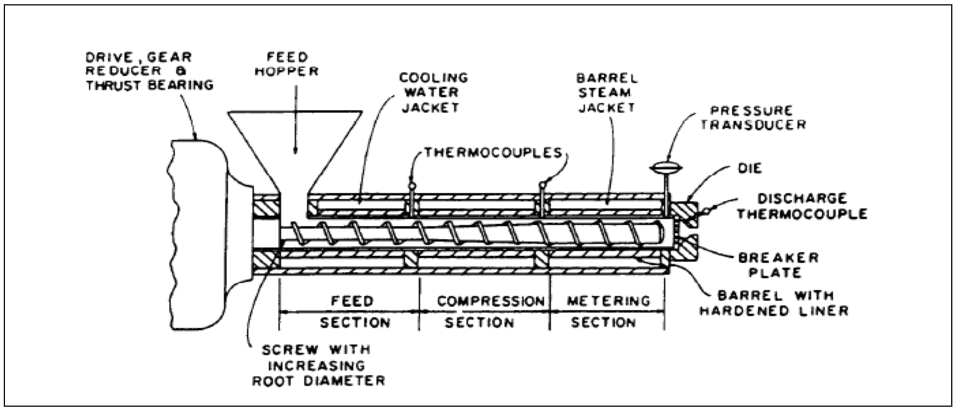


Figure 2-5 : Schematic diagram of single screw extruder

In general a single screw extruder comprises three (3) main sections; feed section, compression section and metering section, as shown in **Figure 2-5** and **Table 2-5** describes their functions.

Table 2-5 : Functions of Extruder Sections

Section	Function
Feed	Carried and compacted solid materials to the compression section.
Compression	Completed the melting process of melt materials.
Metering	Heats and conveys melt materials to the die. Develops high shear rates and pressure

2.5.4.2 Twin- Screw Extruder

The use of twin-screw extruders has rapidly increased the number of extruded products (Bhattacharya, Sivakumar & Chakarborty., 1997). Twin screw extruder can be divided into four types, based on the direction of screw rotation, which are:

(a) Counter-rotating intermeshing
(b) Counter-rotating non-intermershing
(c) Co-rotating intermeshing
(d) Co-rotating non-intermeshing

The type of twin-screw extruder used in this study has a high shear and co-rotating twin-screw. The main processing variables which must be considered when operating a twin-screw extruder are:

- Screw profile
- Screw speed
- Die design
- Barrel temperature
- Feed rate

Figure 2-6 : A twin- screw extruder Clextral BC21, Firminy Cedex, France at Massey University, New Zealand

Figure 2-6 above shows the twin screw extruder available at Massey University, New Zealand which has been used to extrude the pumpkin-corn grits expanded product throughout the study.

2.5.5 Comparison of Single Screw and Twin Screw Extruders

Table 2-6 : Comparison of single screw and twin screw extruders

	Single screw	Co-rotating twin screw
Self-wiping	No	Yes
Mixing	Poor	Good
Uniformity of shear rate	Poor	Good
Heat Transfer	Poor	Good
Moisture range (%)	12-35	6-very high
Flexibility	Narrower	Wider

Table 2-6 shows the differences between single and twin screw extruders.

2.5.6 Principles of Extrusion Cooking

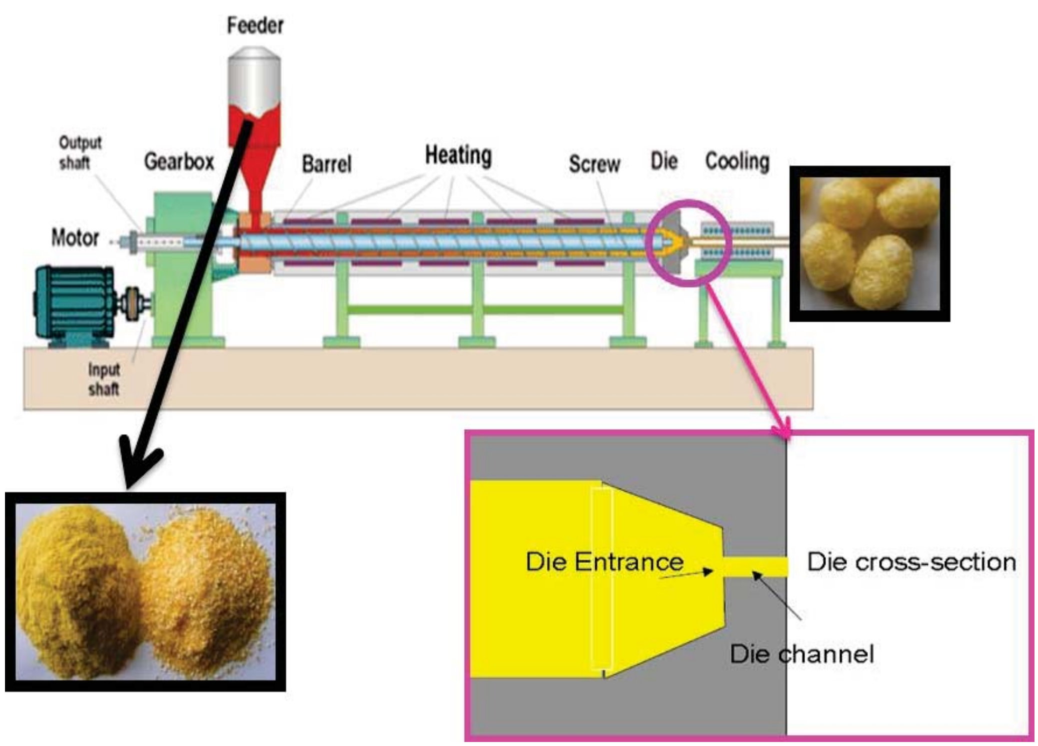


Figure 2-7 : Schematic diagram of twin screw extruder components

The basic components of a twin screw extruder are shown in **Figure 2-7** above. Raw ingredients enter the feeder and came out through the die. High temperature and screw movement inside the extruder, generates the pressure and heat which results in the raw ingredients becoming a melt fluid. The bubble will start to develop as the melt fluid is exposed to steam vapour (superheated), followed by a rapid drop in pressure and temperature upon exiting the die, this will expand the bubble and by end of the die a light expanded product will be produced.

Generally extrusion cooking involves a few extrusion parameters and ingredient as well as changes on chemical nutrients such as starch, protein, lipid, vitamin and bubble formation development. Therefore the subsequent section will cover this topic.

2.5.6.1 Variables and Parameters Involved In Extrusion Processing

Variables and parameters involved in extrusion processing are as follows:

i. Raw Materials
   - Composition – starch, protein
   - Moisture
   - Particle size
   - Additives

ii. Operational variables
   - Feed rate
   - Screw speed
   - Cutter speed
   - Screw profile
   - Barrel temperature
   - Water addition

iii. System parameters
   - Product temperature
   - Product pressure
   - Melt viscosity
   - Thermal energy
   - Specific mechanical energy (SME)
   - Residence time

iv. System disturbances
   - Ambient conditions
   - Screw wear

v. Die profile
   - Open area
   - Flow resistance

vi. Product quality
   - Product moisture
   - Expansion
   - Bulk density
   - Texture
   - Gelatinisation
   - Dextrinisation
   - Morphology – size, shape, uniformity

(Campanella, Li &Ross, 2002)

The interaction between variables and parameters are shown in **Figure 2-8** below:

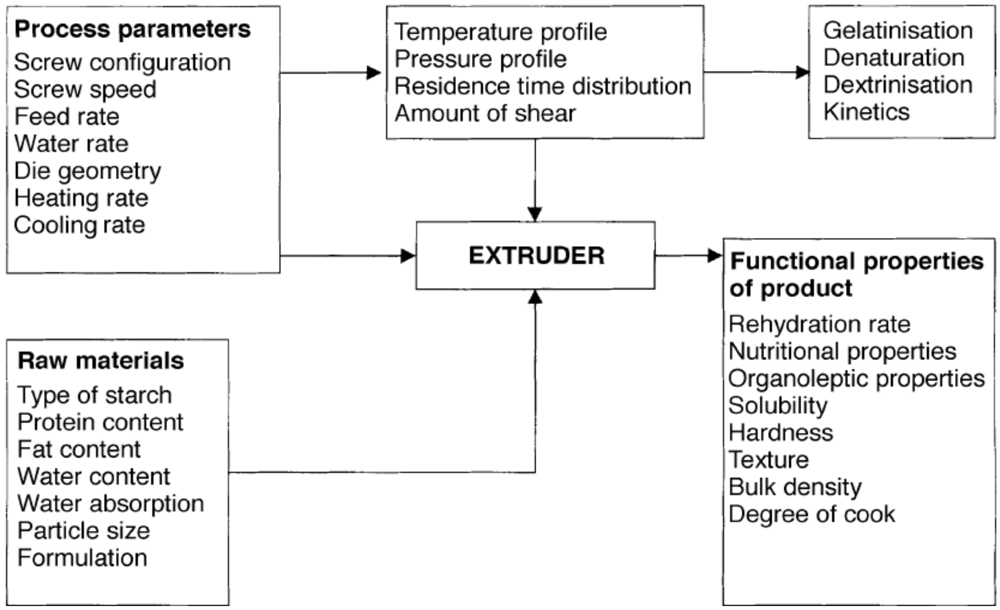


Figure 2-8 : Interaction of raw material properties, process variables and product characteristics (Chessari & Sellahewa, 2001)

2.5.6.2 Factors Influencing the Extrusion Process

The effect of raw materials and extruder operating conditions, particularly mass flow and screw speed during extrusion processing, will be covered. Further discussion on results obtained will be discussed in **Chapter 5.** Understanding these factors is important to compensate for the steady state disturbances and maintain final product quality.

2.5.6.2.1 Mass Flow Rate

Mass flow is referred to as the feed rate which influences the flows of raw materials through the barrel during extrusion processing and the final product quality. Harper (1981), stated that an efficient raw material feed rate in a twin screw extruder gives advantages in eliminating or minimising the pressure and leakage of the raw materials flow. Moreover it is controlled by the direction of screw shape, screw rotation, the relative position of the screw sections and screw configuration (Noguchi, 1989). A stable and steady flow rate of raw materials must be achieved during processing in order to avoid large variation in product quality particularly poor shape, uneven texture and large size distribution of the product. Therefore, the feed rate must be calibrated before extruding the raw materials, thus giving a constant feed rate.

2.5.6.2.2 Screw Speed

The movement of raw materials is due to the rotation of the screw (known as the screw speed) by an electric motor inside the barrel which affects the degree of fill, the duration that materials remain inside the barrel (residence time distribution) and the pressure on the product (Prabhat, Sandeep & Sajid, 2010) An increase in screw speed lowers the melt viscosity of materials due to lowered shear rate thus the materials become less viscous and there is a drop of die pressure during the extrusion processing (Guha, Ali, & Bhattacharya,1998). However, Harper (1981) found that screw speed had only minor effects on final product quality.

2.5.6.3 Bubble Formation During Extrusion

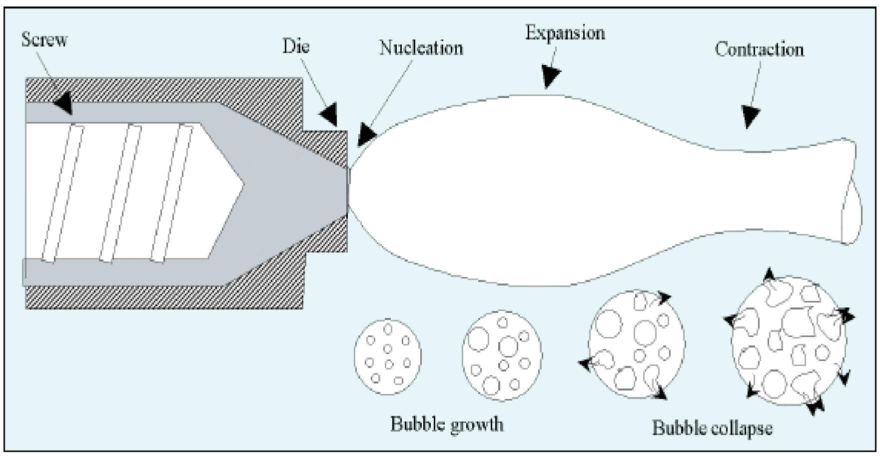


Figure 2-9 : Schematic diagram of bubble formation during extrusion (Moraru et al., 1992)

The structure and texture properties of extruded products which are airy, porous, brittle and expanded are due to bubble formation during the extrusion process. Formation of bubbles involves five (5) major steps: order-disorder of starch molecular, nucleation, extrudate swelling, bubble growth and bubble collapse. These processes are shown in the schematic in **Figure 2-9** and explanation for each processes are discussed below.

A. Order-disorder of starch molecule

   This step occurs at the extruder die, where the homogenous melt of raw materials is exposed to high temperature and high pressure that alters the starch molecule and rheological of the physical starch.

B. Nucleation

Nucleation of the bubble starts as the melt materials exit the extruder die.

C. Extrudate swell

As the temperature is still higher than boiling temperature, the bubble expansion starts to gives rise to the product structure and formation of crust as the product grows.

D. Bubble growth

The difference in pressure between the inside and outside of the product leads to uneven growth of the bubble, so bubble growth at the centre expand more than those at the surface.

E. Bubble collapse

At this final stage, as the product starts to cool, the temperature and pressure drops, the bubble expansion stops and collapses, due to both the cooling and increase in total solids (due to water loss as steam) the viscosity of the extrudate increases and the foam structure sets.

Bubble formation in pumpkin flour – corn grits expanded snacks will be determined and discussed in section **7.2.6**.

2.6 Raw Materials For Extrusion

Common food ingredients that have been used in food extrusion are cereal-based ingredients such as maize, wheat, rice, oat and barley as the major ingredient, while non-major ingredients include tuber sources, potato and tapioca. Vegetable powder such as pumpkin flour is rare in snack processing. All ingredients provide different functional roles in terms of formation, stabilisation, colour, flavour, texture and nutritional qualities of the extruded products (Guy, 2001).

This section will briefly outline two main ingredients that have been used in this study which were pumpkin and corn. Chemical and nutritional changes of the raw material components also will be covered.

2.6.1 Pumpkin

2.6.1.1 Introduction

Pumpkin is a fruit vegetable, native to the Western Hemisphere. It can also be found in North America, Continental Europe, Australia, New Zealand, India and some other countries. In addition, pumpkin has also been cultivated in tropical Asia and countries such as Indonesia, Malaysia and the Philippines (Tindall, 1983). About 1,500,000 ha of pumpkins, squash and gourds were harvested in 2005. Asia and Europe were the main producer. Together, these regions produced nearly 19 million tonnes (FAO, 2006)

Pumpkins and banana can be found in abundant supply in Malaysia (Normah & Ponjata, 2000). Noor Aziah and Komathi (2009) reported that 10,224 metric tonnes of pumpkins were produced in 2007 for local consumption in Malaysia. Pumpkin is a yellow-coloured fruit and is a good source of pro-vitamin carotenoids. Pumpkin is also rich in carbohydrate, pectin, mineral salts and vitamins (Wang &Zhao, 1998; Wang, Liu, Zhao & Hoa.,2002). Pumpkins are grown widely as a replacement for tobacco crops in the tabacco-growing areas of Kelantan, Malaysia. Pumpkins is mainly used as a vegetable food and is also served as a traditional dish by cooking it in a heavy syrup of palm sugar. It is also widely used in the preparation of traditional cakes and as a base in other foods including jams and soups.

Increased use of pumpkin and its co-products will also enhance the utility and versatility of the pumpkin crop in Malaysia. Yet few investigations of this product and its applications have so far been carried out (Normah & Ponjata (2000), Noor Aziah & Komathi (2009)). The versatility and profitability of the pumpkin crop could be extended by diversifying crop use and utilising products such as pumpkin peel and seed. This could contribute to maximising the available resources and result in the production of various new products thus minimising the agricultural by-product waste.

Various parts of the pumpkin plant and pumpkin fruit can be eaten. Longe, Farinu and Fetuga (1983) noted that young green leaves are delicious as a vegetable. The kernels of pumpkin seeds are often used as additives to some food dishes as reported by Nwokolo and Sim (1987). Koike, Li, Liu, Hata and Nikaido (2005) stated that pumpkin has been used as a vegetable since antiquity. In addition, pumpkin seeds have often been used as snacks. Lazos (1986) stated that pumpkin seed is high in protein content that ranged from 25.2 to 37% and oil that ranged from 37.8 to 45.4%.Pumpkins are commonly cooked and served as a vegetable such as pumpkin pie, pumpkin bread, pumpkin soup and roasted pumpkin. Ptitchkina, Danilova, Doxastakis, Kasapis and Morris (1994) stated pumpkin can also be used as a gelling agent in food jam and jellies. Moreover pumpkin has also been used as forage to feed sheep, pigs and goats (Akwaowo,Ndon & Etuk.,2000). In addition pumpkins are traditionally part of Halloween celebrations in the United States (Radovich,2010).

The orange-flesh types of pumpkin provide an excellent source of vitamin A, which is an important antioxidant. The flesh is also naturally low in calories (Radovich,2010). Pumpkins are among the most economically important plant families being the basis for multi-million dollar industries. The role of pumpkin and its nutritional advantages contribute substantially to its economic value (Kocyan, Zhang, Schaefer & Renner, 2007).

Having considered the common features of the pumpkin plant, the focus now turns to the pumpkin's rating on the Glycaemic Index (GI) scale. Nishimune, Yakushiji, Sumimoto, Taguchi, Konishi, Nakahara and Kunita (1991) found that pumpkin has a high GI value of 75 compared to 100 for white bread. This result was supported by Foster-Powell and Miller (1995). Foods with a lower glycaemic response are associated with reduced risk for chronic disease (Brand-Miller,Foster-Powell & Burani, 2006). Furthermore, foods with a lower glycaemic index may help regulate the satiety mechanism (Roberts, 2000) and body weight (Pereira,Swain, Goldfine, Rifai & Ludwig., 2004). Foods with low GI release glucose more steadily over several hours and this helps to keep blood sugar levels relatively low. Foods with a high GI release glucose into the blood stream quickly. This causes blood sugar levels to rise rapidly and invokes an insulin spike resulting in high insulin release into the blood stream.

The main problem in pumpkin processing is waste stream management. Brian (2008) stated that Cedenco generates approximately 5500 metric tonnes of pumpkin waste during the processing season (January-June). Based on application analyses done by Brian(2008) on Cedenco Foods Ltd, a few suggestions have been made to overcome and manage the waste stream from pumpkin processing; biomass for energy production, biomass for removal of heavy metal, composting, skin products, health products, squash puree, milled pumpkin seeds, pumpkin seed oil and snack foods. However, this may need a feasibility study to be carried out.

In order to enhance the utility and versatility of a pumpkin based food products, breakfast cereals or expanded snack products with a low glycaemic index value are recommended. Breakfast cereals are in high demand due to several factors such as the convenience of these foods, advertising, and the increased interest in dietary fibre and enriched or fortified foods (Gibson, Donovan & Heath, 1997).

Nowadays, extrusion technology is increasingly important in the food industry for transforming ingredients into intermediate or finished products. According to Miller (1988) extrusion cooking is widely used in the production of breakfast cereals. In particular, it has become the most common and versatile technology in the production of cereal based snack foods (Perez-Navarrete, Gonzalez, Chel-Guerrero & Betancur-Ancona, 2006). Moreover Anderson, Conway, Pfeifer and Griffin (1969) also stated that extrusion technology has been widely used in the manufacture of ready-to-eat cereals, expanded products and breakfast cereals.

2.6.1.2 Pumpkin Structure

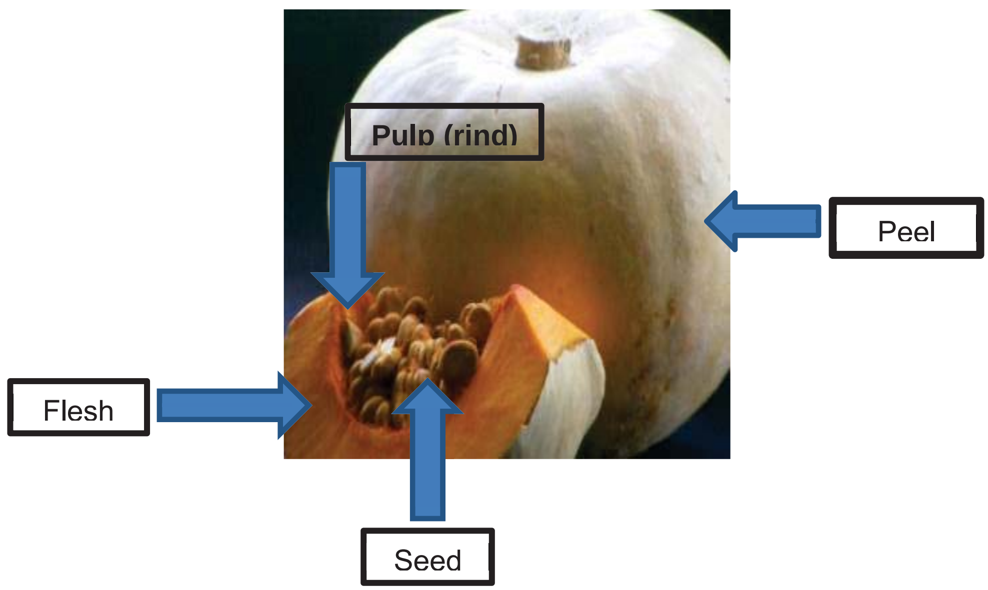


Figure 2-10 : Pumpkin structure

Figure 2-10: shows pumpkin structure which consists of four main parts; peel, flesh, seed and pulp (rind).

2.6.1.3 Plant Species

The FAO (2006) reported that world agricultural production has increased annually by 2.2% over the last ten years. Pumpkin production was found to have increased from 50 million tonnes in 1996 to 203 million tonnes in 2005. In fact, pumpkin production grew faster than average agricultural production. Sidek (1999) stated that *cucurbitaceae* (pumpkin family name) is the third largest family of fruit vegetable crops grown in Malaysia after solanaceace and leguminosae in terms of hectarage. Almost all of the cucurbits were grown for local consumption.

The pumpkin plant grows as a vine or as a compact bush. Pumpkin fruit is large and varies in shape from more or less spherical to flattened or oblong. The colour of pumpkin ranges from dark green, pale-green, orange-yellow, white, and red to gray (Tindall, 1983). The *cucurbitaceace* family consists of 119 genera and 825 species (Vanhanen, Savage & Dutta., 2005) which include C*ucurbita maxima, Cucurbita moshata, Cucurbita pepo,and Cucurbita mixta .*

Cucurbita maxima, known as the King of Mammoths, Big Max, Big Moon or Atlantic Giant, is the largest in size sometimes exceeding 300kg. In New Zealand this species is the fourth largest fresh horticultural crop for export after apples and kiwifruit (Bycroft, Corrigan & Irving., 1999). In addition C*ucurbita maxima* is the most important species in South America (Linskens & Jackson, 1994). The matured fruits are cooked as a vegetable and used in jams and pies. *Cucurbita moschata* is bell-shaped and is commonly known as butternut squash. In the Middle East it is known as “Tripolitan”. This species is quite large with some in excess of 100kg. *Cucurbita moschata* is suitable for use in pies and jams, while “mammoth” cultivars are mainly used for stockfeed. According to Wenli, Yaping, Jinjing and Bo (2004), *Cucurbita moschata* is one of the most popular snack and main food resources planted in China. Moreover, its seed is commonly used for salad oil production in Austria, Slovenia and Hungary (Murkovic, Hillebrand, Winkler & Pfannhauser, 1996).

2.6.1.4 Nutritional Value of Pumpkin

The nutritional composition of pumpkin is shown in **Table 2-7.** The major component of raw pumpkin is moisture (91.6%) which varies according to variety, maturity, growing conditions, season and fraction that is consumed (Hart & Scott, 1995). *Cucurbita moschata* was found to have a high fibre content, and to be low in sugar and lipids (McCance & Widdowson, 1991). The content of carbohydrate varies greatly between species of pumpkin (Nishmune et al., 1991). The average total dietary fibre (TDF) in pumpkin was found to be 1.57%.

Table 2-7 : Proximate composition, Total dietary fibre and energy of raw pumpkin (edible part),(USDA National Nutrient Database For Standard Reference, 2005)

Nutrient	Percentage of wet weight basis (% w.w.b)
Protein	1.00
Fat	0.10
Ash	0.80
Carbohydrate	6.50
Moisture	91.60
Total Dietary Fibre	0.5
Energy	26 kcal/100g

Raw pumpkin was found to be a good source of β-carotene, which is a major source of Vitamin A (Lee, 1983). Vitamin A is essential for maintaining good eyesight as well as a healthy immune system (Bendich, 1989). The amount of vitamin A present range substantially even within varieties (Holmes & Spelma, 1946). Normah and Pongjata (2000) stated that pumpkin is one of the most reliable, cheapest and affordable sources of vitamin A.

Young cucurbita fruit are very low in carotenoids and have pale-coloured flesh (Linsken & Jackson, 1994). Park (1987) stated that carotenoid in vegetables and fruits remains stable throughout the cooking procedure. However, Gayathri, Platel and Srinivisan (2003), found that the loss of β-carotene from pumpkin was greater than that from carrot during heat treatment, but the retention of β-carotene was higher in boiled pumpkin with the addition of tumeric.

Total carotenoid was found to be 12μg/g-26μg/g in *Cucurbita maxima* (Lee, Smith & Robinson., 1984), whereas in *Cucurbita pepo* it was 3 μg/g - 52.1 μg/g (Schaffer, Paris & Ascarellil., (1986); Paris, Schaffer, Ascarelli & Burger.,(1989)). Furthermore in *Cucurbita moschata*, carotenoid was found to be 8 μg/g - 16 μg/g. Therefore, *Cucurbita pepo* has a higher carotene content then either *Cucurbita maxima* or *Cucurbita moschata*. Chavasit, Pisaphab, Sungpuag, Jittinandena, and Wasantwisut (2002), found that there was an increase in β-carotene content in fresh whole pumpkin after three month storage. Pumpkin is also a good source of water-soluble vitamins – B1, B2, niacin and vitamin C. Moreover the content of vitamin E in pumpkin seeds is very high (Murkovic, Piironen, Lampi, Kraushofer & Sontaq, 2004). It is also high in minerals – potassium, manganese and copper.

2.6.1.5 Food Products Containing Pumpkin Fractions

Pumpkins have a large range of uses as a potentially valuable food for humans and animals. The flesh is eaten fresh cooked as a vegetable or used as a flavour ingredient in pies, bread and soups. When dried as a powder or flakes it is used in foods ranging from sauces to jams. Its activities range from flavour and colour to thickener.

Pongjanta, Nauburang, Kawngdang, Manon & Thepjaikat (2006) produced pumpkin powder which was utilised in some bakery products; sandwich bread, sweet bread, butter cake, chiffon cake and cookies. Analysis showed that pumpkin powder was found to significantly enhance β-carotene in the bakery products described above.

Lee, Cho, Lee, Koh, Park & Kim (2002) found that noodles made from pumpkin powder were more attractive with their yellow colour and were the most popular in terms of appearance, taste, texture and acceptability. In Portuguese cuisine, raw edible pumpkin has been used as a base for soup and desserts (Goncalves, Pinheiro, Abreu, Brandao & Silva., 2007). Rheological and thermal characteristics of pumpkin puree have been studied by Dutta,D., Dutta,A., Raychaudhuri and Chakraborty (2006). Pumpkin puree is an intermediate product that is mainly used for the manufacture of jams, jelly, sweets, beverages and other products.

Pumpkin flakes were developed to act as a carotene source for infant (weaning) foods by Fernandez, Guerra, Diniz, Salgado, Guerra, Lopes, Neta and Padilha (1998) and also Jirapa, Normah, Zamaliah, Asmah and Mohamad (2001). Egbekun, Nda-Suleiman and Akinyenye (1998) found that there was no significant difference in acceptability between pumpkin marmalade and commercial orange marmalade. In India, pumpkin is commonly used for making kofta that is normally used in curry preparations (Teotia, Saxena, Berry & Anuja, 2004).

Pumpkin seed in Nigeria has been used as an ingredient in a variety of local food that is known as ogiri (Al-Khalifa, 1996). Recently, much research has been carried out investigating the pumpkin seed as a valuable source of oils and protein. Defatted pumpkin seed flour was high in protein (Lazos, 1986) and El-Soukkary (2001) found pumpkin seed protein increased the lysine and mineral content of bread. Fermented pumpkin seed can also be used as a flavouring agent or protein supplement in a variety of local foods (Achinewhu,1987; Banigo & Akpapunam,1987). Pumpkin peel is rich in pectin, which can be used as a gelling agent and thickening agent as well as acting as a stabilizer in food (Jun, Lee, Song & Kim, 2006). Table 2-8 summarises the research on pumpkin fractions.

Table 2-8 : Summary of food products containing pumpkin fractions

Pumpkin Fraction	Uses	References
FLESH / PULP	1. Vegetable	Longe et al.,(1983)
	2. Pumpkin puree- for jellies, sweets, beverages	Dutta et al., (2006)
	3. Thickener in jam 4. Filling in pie	Ptitchkina et al., (1994)
	5. Powder/flour- in bakery products: sandwich bread, sweet bread, butter cake, chiffon cake, cookies, wheat bread, asian noodles	Pongjanta et al., (2006)
	6. Pumpkin flakes	Fernandez et al., (1998), Jirapa et al., (2001)
	7. Marmalade	Egbekun et al., (1998)
	8. Portuguese cuisine – Base for soup and dessert	Goncalves et al., (2007)
	9. Shredded pumpkin – Kofta (Indian food)	Teotia et al., (2004)
	10. Ogiri	Al-Khalifa (1996)
	11. Animal feed – Forage	Akwaowo et al., (2000)
SEED	1. Oil	Wenli et al., (2004)
	2. Flour/Powder – flavouring, snack, additives, loaf improver, incorporated in sausage, weaning foods and bread	El-Soukkary (2001), Achinewhu (1987), Banigo & Akpapunam (1987)
PEEL/SKIN	1. Pectin – gelling Agent, thickening, stabilising agent	Jun et al., (2006)

2.6.1.6 Commercial Pumpkin Products in New Zealand and Australia

Pumpkin crops in New Zealand and Australia have been commercialised into a few products ranges. Cedenco Foods Ltd New Zealand manufactures several ranges of pumpkin products for the local and Japanese markets. The products are pumpkin powder, frozen puree, individually quick frozen (IQF) pieces and IQF diced pieces. Heinz Wattie's Ltd New Zealand has produced baby food and soup made from pumpkin. In the local supermarket, Woolworths and Countdown in New Zealand, pumpkin seeds are sold as snack foods as Fresh Zone™ pumpkin seeds and Tasti™ pumpkin seeds. The Australian Pumpkin Seed Company in Australia produces and sells pumpkin seed meal and pumpkin seed oils as a nutritional supplement, also pumpkin seeds that are coated in either milk or dark chocolate in small packages. The latest product is chili coated pumpkin seed. However, no expanded snacks are made from pumpkin flour in either country.

2.6.2 Corn

2.6.2.1 Introduction

Maize or corn is the third most important crop worldwide and commonly has been used as a base ingredient in the snack industry. In general, there are several uses of corn in food as well as feed industry such as the production of flour, corn meal, grits, sweeteners, starches, alcoholic beverages, cooking oil, tortilla, snacks, breakfast foods and other products. Dry-milled corn meal is the most common primary ingredient used in corn-based extruded snacks.

2.6.2.2 Corn Kernel Structure and Types

Corn kernel is referred to as a seed in the form of a single fruit coat comprised of pericarp, endosperm and germ as shown in **Figure 2-11** below.

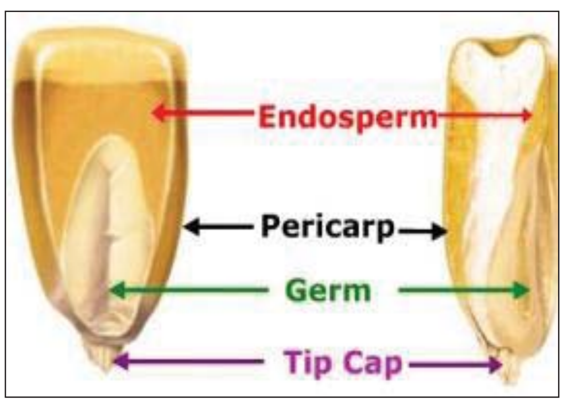


Figure 2-11 : Components of corn kernel

Table 2-9 : Kernel structures and their functions

Kernel Structure	Characteristics and Functions
Pericarp (Hull/Bran)	• As a protector for internal parts • Thickness : 25 to 140µm • Dry kernel weight : 5-6%
Endosperm	• Represents majority of the kernel • Dry weight : 82-84% • Composed of 86-89% starch granules
Embryo (Germ)	• Contains 81-85% oil • A dorman young corn plant • Dry weight : 10-12%

Table 2-9 above describes the parts of the corn kernel and their functions.

2.6.2.3 Corn for Food Industry Processing

Corn is processed into a wide variety of products. Basically most corn processed for the food industry either by wet or dry milling. A summary of corn uses in the food industry is shown in **Table 2-10.**

Table 2-10 : Summary of corn uses in food industry processing (Serna-Saldivar, Gomez, & Rooney, 2001)

Corn fraction	Food Industry Processing and Applications
Whole Corn	1. Alkaline cooked products 2. Industrial tortilla production 3. Fried products- snacks 4. Nixtamalized dry masa flours 5. Hominy 6. Cornuts and parched products
Dry milled corn fraction	1. Flaking grits : cornflake production 2. Corn grits – brewing, distillation, breakfast foods, extruded snacks, arepas 3. Corn meal 4. Corn flour

2.6.2.4 Dry Milled Corn Fractions

Dry milling of corn produces the maximum output of clean grits, with less fat, fibre and speck from the hilum. **Table 2-11** shows the percentages of dry-milled fractions.

Table 2-11 : Typical yields of corn dry-milled fractions

Product	Yield (%)
Flaking grits	12
Coarse grits	15
Regular grits	23
Coarse meal	3
Dusted meal	3
Flour	4
Oil	1
Hominy feed	35
Shrinkage	4

2.6.2.5 Dry Milled Corn Fractions for Extruded Snack Processing

The unique characteristics of corn resulted in it becoming the choice of most snack processors for use in corn-based extruded snacks especially in terms of starch content which has good expansion characteristics, it also has a definite flavour with a natural yellow colour.

2.6.2.6 Nutritional Value of Dry Milled Corn Fractions

In general, typical dry-milled corn consists of nutrients as shown in **Table 2-12** below.

Table 2-12 : Composition of dry-milled corn grits (Watson & Ramstad, 1987)

Component	Percentage (%)
Moisture	11.5
Protein	7.5
Fat	0.7
Crude fibre	0.2
Ash	0.3
Starch	78
Other Polysaccharides	1.8

2.6.3 Nutrient Components: Chemical and Nutritional Changes in Food During Extrusion

Extrusion - cooking has a great effect on chemical and nutritional changes in nutrient components of raw materials. The raw materials may undergo many chemical and structural transformations such as starch gelatinisation, protein denaturation, complex formation between amylose and lipids and degradation reactions of vitamins and pigments (Ilo & Berghofer.,1999).

Table 2-13 : Functional role of raw ingredient components

Component of raw ingredient	Functional Properties
Starch, Protein	Structure-forming materials
Protein, Starch, Fibre, Oils (Lipid)	Dispersed-phase filling materials
Water, oils and fats	Plasticisers and lubricants

2.6.3.1 Carbohydrate

Three main types of carbohydrate are affected by extrusion cooking: starch, fibre and sugar.

2.6.3.1.1 Starch

Starch is the dominant polymer and plays an important role in the extruded products by giving them expansion (Moraru & Kokini, 2003), binding and “mouthfeel”. Moreover starch is the largest food component that provides the structure formation of the extrudate products (Prabhat et al., 2010). In general the roles of starch in the extrusion processing are density control, strength, shelf life improvement, moisture uptake, flavour, water holding capacity and fat binding (Feldberg and Smith as cited in Harper, 1981).

Fundamentally starch is composed of amylose and amylopectin. Different types of food may have different amounts of amylose and amylopectin. Amylose is a linear molecule of glucose units linked by α-(1-4) bonds. Typically amylose consists of 100-1000 glucose units. Amylopectin is a branched molecule with linear regions of α-(1-4) linked glucose units and α-(1-6) linked branch points. The structure of amylose and amylopectin are shown in **Figure 2-12** and **Figure 2-13** respectively.

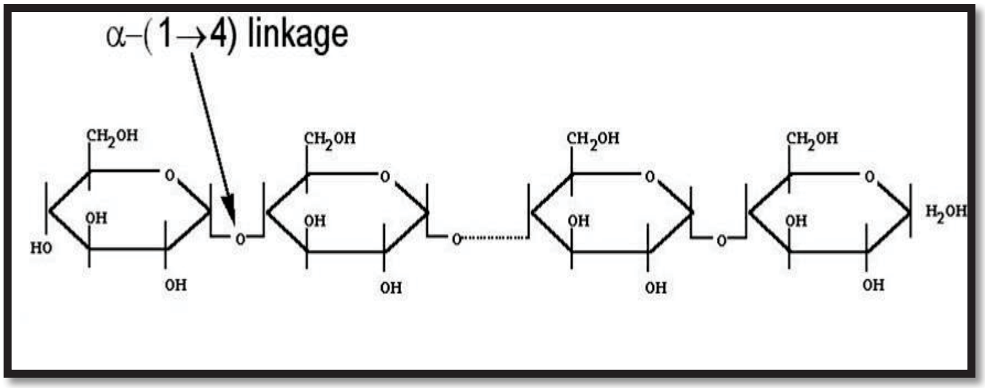


Figure 2-12 : Amylose structure

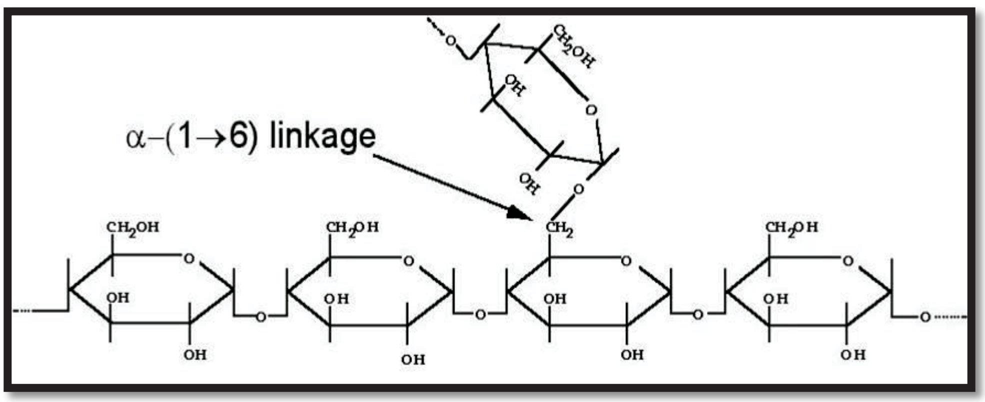


Figure 2-13 : Amylopectin structure

The degree of expansion is greatly affected by the amylose and amylopectin ratio. High amylopectin contents result in light, elastic and homogenous expanded texture. High amylose content in contrast results in a hard, less expanded extrudate. Amylopectin promotes puffing and results in a very light, fragile extruded product (Murray et al., as cited in Harper 1981). **Table 2-14** below shows amylose and amylopectin content from various starches source.

Table 2-14 : Amylose and amylopectin content of various starches (Harper, 1981)

Starches	Percentage (%)	
	Amylose	Amylopectin
Standard maize	24	76
Waxy maize	0.8	99.2
High amylose maize	70	30
Potato	20	80
Rice	18.5	81.5
Tapioca	16.7	83.3
Wheat	25	75

2.6.3.1.2 Starch Structure Changes during Extrusion

Extrusion processing results in starch gelatinisation, partial starch hydrolysis and also affects the pasting properties. In general, starch gelatinisation or cooking starch through extrusion processing converts raw indigestible starch into digestible starch with the presence of heat and moisture (Lawton, Henderson & Derlatka, 1972). Starch granules irreversibly lose their regular shape and properties and become more soluble. Gelatinisation temperature varies among ingredients, such as maize 62°-80°C, wheat 52°-82°C, tapioca 52°-65°C and potato 58°-65°C. A part from the extrusion process, some of the starch also undergoes hydrolysis. Changes to the starch granules affect the final viscosity of the starch.

2.6.3.1.3 Fibre

Fibre or dietary fibre is referred to as the non-digestible components of plant cell walls, and consists of a group of polysaccharides such as pectin, cellulose, hemi-cellulose, mucilage, lignin and other substances i.e cutin, suberin and waxes (Devries, Prosky, Li & Cho, 1999). It can be categorised into two types; soluble (pectin, glucan, soluble pentosans) and insoluble dietary fibre (cellulose, lignin, insoluble pentosans, protopectin). Huber (2011) stated that fibre is chemically resistant to heat during extrusion processing which may affect the expansion of the extruded product. This was supported by Mendonca, Grossmann and Verhe, (2000) who found that fibre content in the form of bran results in premature rupture of gas cells, thus reducing overall expansion. Fibrous fragments disrupt the starchy film of air cell walls, reducing their formation and swelling, and altering air cell size. As pumpkin was found to have high pectin content it may be expected to affect the physical output of the expanded snack product.

2.6.3.2 Protein

Protein may become denatured and change from soluble to insoluble forms during the extrusion process. The denaturation process occurs at 60-70°C and as a result will become less functional and lead to reduced expansion of final extrudates.

2.6.3.3 Lipids

Materials with a high fat content may not extruded. Riaz (2000) stated that a lipid content of more than 5-6% will impair the extruder performance by decreasing the torque value. As a consequence this will contribute to poor product expansion.

Chapter 3: Characterisation and Production of Pumpkin Flour

3.1 Introduction

This preliminary work will focus on exploring and processing of fresh pumpkin into flour. Two types of pumpkin crown and buttercup were used with two drying methods, convection oven and freeze drying. The objectives of this work were to produce pumpkin flour from the entire pumpkin fractions such as peel, pulp(rind), flesh and seed. Then use the pumpkin flour as an ingredient in making the expanded snack products. The proximate composition and colour value of the pumpkin flour were determined. The results from this work were compared with commercial pumpkin flour made by Cedenco Foods Ltd.

3.2 Materials and Methods

3.2.1 Raw Materials

Mature crown and buttercup pumpkin (*Cucurbita maxima*) were purchased fresh from the local market. Pumpkin flour was supplied by Cedenco Foods Ltd, Gisborne New Zealand. Corn grits (Spec 220) were supplied by Corson Grain Ltd Gisborne, New Zealand.

3.2.2 Sample Preparation

Pumpkins were diced and separated into four fractions; peel, flesh, pulp(rind) and seed. Then all fractions were soaked in 0.1% citric acid for 30 minutes and drained. The purpose of soaking in citric acid was to prevent unfavourable changes in pumpkin colour and flavour deterioration (Konopacka, 2006). Pumpkin flour was produced using two (2) methods of drying, convection oven and freeze drying as described in sections **3.2.2.1** and **3.2.2.2** below.

3.2.2.1 Pumpkin Flour Production Using Convection Oven

All four fractions of pumpkin (peel, flesh, pulp and seed) were transferred to wire-net trays and dried in the hot air drier for 24 hours at 65°C and 40% humidity. The dried fractions were ground into flour using a grinder and vacuum packed for further use.

3.2.2.2 Pumpkin Flour Production Using Freeze Drying

The samples were freeze dried using a pilot plant freeze drier (Cuddon FD 18LT). The samples were frozen at -30ºC overnight prior to freeze-drying. The samples then were placed between metal sheets, which were heated at 25ºC at a chamber pressure of 0.1mbar for 3-4 days.

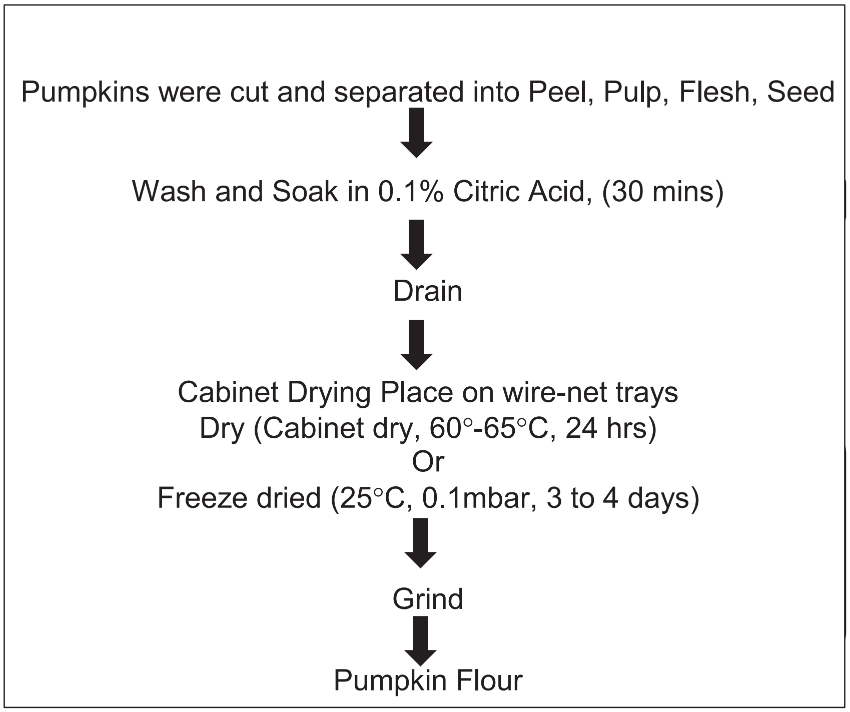


Figure 3-1: The production process for pumpkin flour

3.2.3 Proximate Analysis

Moisture, ash (AOAC method No.945.18), fat (AOAC method No. 945.16) and crude protein (AOAC method No. 920.53) were determined by the AOAC method (1998). A factor of 6.25 was used for conversion of nitrogen to crude protein. Carbohydrates content was calculated by subtracting the content of all the measured components (i.e. moisture, ash, crude fat and crude protein) from total mass. All measurements were expressed on a dry matter basis and reported as a mean (± S.D.) of triplicate analysis.

3.2.4 Colour Measurement

The Minolta Chroma meter (CR-200) was used to determine the Hunter L*, a* and b* values of the samples. Ground samples were placed into small petri dishes and levelled, giving a sample depth of 0.5 cm in order to obtain a uniform colour distribution within the sample. The petri dish was positioned on top of the aperture opening of the Chroma Meter and a tin cup with black interior was balanced on top of the Petri dish to prevent any external light affecting the measurement. The Chroma meter was standardized against a standard white tile prior to use. The colour of the samples was measured in triplicate. The Petri dish was moved slightly for each replicate measurement to get an indication of the variation within the sample.

The meaning of the Hunter L*, a* and b* values is described below:

L* - measures the relative lightness (+100) or darkness (0) of a sample

a* - represents the red (+100) or green (-80) attributes

b* - represents the yellow (+70) or blue (-80) attributes of a sample

3.2.5 Statistical Analysis

All experimental data in this study were analyzed using the General Linear Model (GLM) and Tukey's Studentized Range (Honestly Significant Difference (HSD)) test for a comparison between means using the SAS statistical analysis software program (SAS software version 9.2 (SAS Institute Inc., Cary, NC). Level of significant difference is reported either at the 5%, 1% or greater confidence level ($P<0.05$).Pearson correlation coefficients from trend lines fitted to appropriate data were calculated using Microsoft Office Excel 2007.

3.3 Results and Discussion

3.3.1 Characterisation of Pumpkin and Pumpkin Flour Production

This preliminary work was focused on developing methods of processing the entire pumpkin fractions such as peel, pulp (rind), flesh and seed of fresh pumpkin into flour. Two types of pumpkin (crown and buttercup) with two drying methods, hot convection oven and freeze drying were used. The objectives of this work were to determine the yield of pumpkin flour through processing and to determine the proximate compositions and colour value of the pumpkin flours from different fractions. The results were then compared with commercial pumpkin flour produced by Cedenco Foods Ltd. As shown in **section 3.3.5** and were found to be essentially the same and therefore the pilot plant manufactured flours are relevant to industry. In **sections 3.3.2, 3.3.3,** and **3.3.4** this data characterising the pumpkin flesh and pumpkin flour is correlated with processing parameters during extrusion processing and the quality characteristics of expanded snacks.

3.3.2 Raw Pumpkin

The aim of this experiment was to determine and compare the composition in terms of peel, pulp(rind), flesh and seed of two types of pumpkin; crown and buttercup. Understanding the differences in composition between buttercup and crown will help in understanding and controlling waste during processing. Moreover, it will also give an opportunity to utilise all the pumpkin fractions to form value added products and less waste.

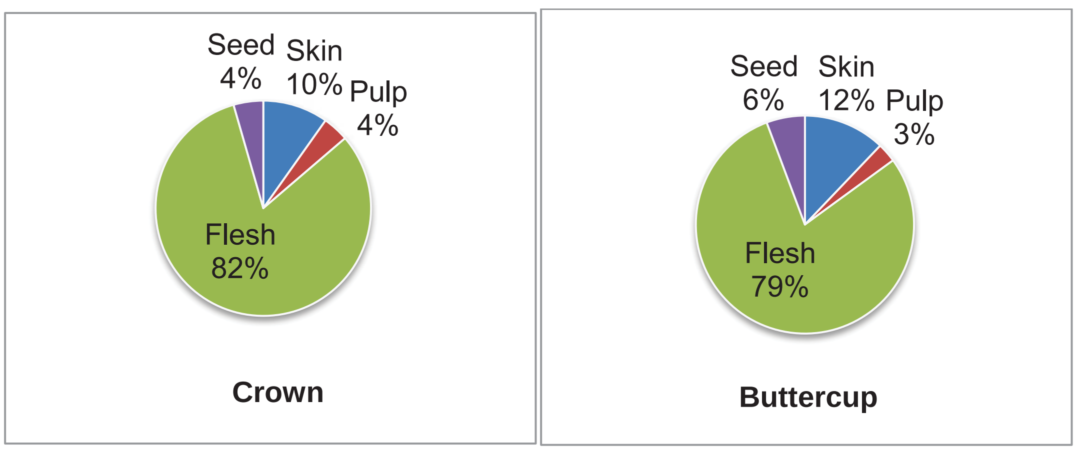


Figure 3-2 : Proportion of two types of pumpkin

Based on data presented in **Figure 3-2,** it is evident that the pumpkins studied in this work have a similar gross fractional composition as follows; 10-12% peel, 3-4% pulp, 79-82% flesh and 4-6% seed. This shows that, if food processing only used the fleshy part of the pumpkin, which is the case with most pumpkin processing, then the waste produced would be between 18% and 21%. **Figure 3-2** above shows that, buttercup had a smaller proportion of flesh compared to crown, and therefore may produce slightly more waste than crown. Cedenco Foods Ltd was found to have pumpkin processing was of approximately 5500 metric tonnes per season out of a total 22000 tonnes of raw pumpkin i.e their waste is 25% (Brian, 2008). The waste was higher due to their processing only the fleshy fraction of pumpkin.

The amount of waste generated from pumpkin processing, however, is not merely the sum of the pumpkin fractions that are intentionally not used. Additionally the separation processes involved in isolating the desired fraction (i.e. the flesh) are not 100% efficient. The peeling process in most food industries normally involves using abrasive peeling and steam peeling (Emadi, Kosse & Yarlagadda, 2007). In this study the peeling process was manually done using knives, this may affect the accuracy of the recovery percentage achieved and if this applied to the industry it may cost and expensive labour. In this study the recovery yield given is based on an estimate, the skin was difficult to peel and some of the flesh remained on the peel.

3.3.3 Pumpkin Flour Production

Sixteen samples of pumpkin flour were produced via the method described in **section 3.2.2**. Four fractions (peel, pulp, flesh and seed) of two types of pumpkin (crown and buttercup) were dried using either freeze drying or convection oven. The relative percentages on a dry weight basis of pumpkin flour produced from four different fractions of two types of pumpkin using different types of drying methods are presented in **Figure 3-3** below. For both types of pumpkin, flour made from seed fractions using freeze drying gave the highest yield of flour (52.15% (crown), 47.08% (buttercup) followed by peel, flesh and pulp as compared to convection oven. Pulp fractions were difficult to separate and gave the lowest yield of flour for both types of pumpkin and both types of drying methods. Due to the difficulties of isolating pulp fractions further physicochemical analysis focused only upon the three fractions (peel, flesh, and seed) of each variety of pumpkin for both methods of drying.

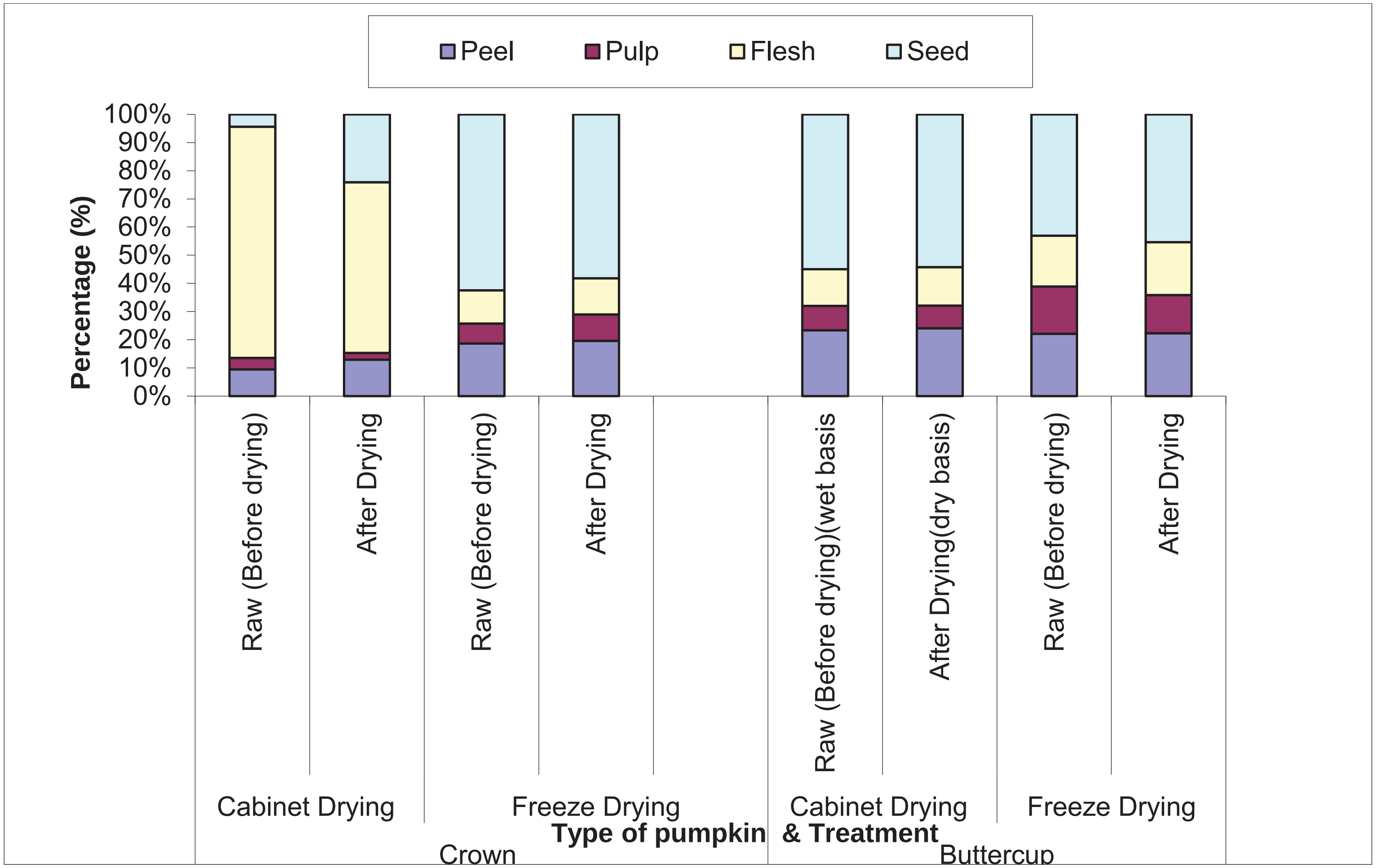


Figure 3-3 : Recovery yield of pumpkin flour (dry weight basis)

3.3.4 Proximate Composition of Raw Pumpkin and Pumpkin Flour

The proximate composition of moisture content, ash, protein, fat and carbohydrate of the pumpkin flour from three fractions (peel, flesh, and seed) of two types of pumpkin (crown and buttercup) with two different drying methods are presented in **Table 3-1.**

Significant differences (P<0.05) were found in a number of areas in terms of type of pumpkin, drying method and fractions. For both varieties, drying methods showed a significant effect (P<0.05) on the moisture, ash, protein, fat and carbohydrate content. Flour produced by freeze drying for both varieties showed the lowest value of moisture content (2.63 – 14.99%).

The preliminary result in this study, revealed that the nutritional values of pumpkin flour produced by freeze drying compared with convection oven drying were not significantly different. However, Que,Mao,Fang and Wu (2008) stated that freeze drying is the most effective way of protecting against loss of nutrients during the drying process. These observations need to be further investigated in terms of method of flour preparation, equipment used and a storage study.

Commercial pumpkin flour (**Table 3-2**) produced by Cedenco Foods Ltd that has been processed by drum drying was found to have a lower moisture content (1.8%) as compared to convection oven drying (9.44 – 14.43%) and freeze drying (4.91% - 14.99%). Overall other nutrient contents such as protein, carbohydrate and ash were found to vary among fractions but did not much differed from commercial pumpkin flour.

Table 3-1 : Proximate composition of raw pumpkin and pumpkin flour prepared from different fractions of two (2) types of pumpkin prepared by different drying methods

Pumpkin	Processing	Fractions	Moisture(%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)
Crown	Raw	Peel	89.52 ± 0.06^{b}	9.83 ± 0.25^{a}	0.32 ± 0.02^{m}	0.03 ± 0.00^{f}	0.29 ± 0.28^{j}
		Flesh	94.34 ± 0.13^{a}	8.20 ± 0.13^{b}	0.29 ± 0.02^{m}	0.28 ± 0.03^{c}	6.89 ± 0.39^{k}
		Seed	47.85 ± 0.45^{e}	3.45 ± 0.04^{e}	2.85 ± 0.10^{j}	0.09 ± 0.003^{f}	45.76 ± 0.49^{i}
	Convection oven Drying	Peel	10.31 ± 0.04^{i}	6.50 ± 0.10^{d}	1.96 ± 0.02^{k}	0.27 ± 0.03^{c}	80.95 ± 0.10^{c}
		Flesh	14.43 ± 0.15^{h}	5.62 ± 0.08^{e}	1.30 ± 0.02^{l}	0.04 ± 0.005	78.60 ± 0.09^{d}
		Seed	6.37 ± 0.07^{l}	$2.50 \pm .03^{m}$	4.09 ± 0.02^{i}	0.23 ± 0.01^{d}	86.81 ± 0.07^{b}
	Freeze Drying	Peel	6.43 ± 0.11^{l}	8.36 ± 0.05^{e}	7.57 ± 0.05^{e}	0.05 ± 0.02^{f}	77.44 ± 0.26^{e}
		Flesh	14.99 ± 0.07^{g}	7.73 ± 0.07^{c}	4.88 ± 0.17^{g}	0.04 ± 0.02^{f}	72.35 ± 0.28^{f}
		Seed	5.00 ± 0.08^{m}	3.90 ± 0.27^{j}	21.28 ± 0.39^{a}	0.05 ± 0.02^{f}	69.77 ± 0.76^{g}
Buttercup	Raw	Peel	78.27 ± 0.05^{d}	4.26 ± 0.29^{i}	1.89 ± 0.09^{k}	0.33 ± 0.005^{b}	0.29 ± 0.28^{m}
		Flesh	84.86 ± 0.14^{e}	4.69 ± 0.29^{g}	0.48 ± 0.03^{m}	0.08 ± 0.001^{f}	6.89 ± 0.02^{l}
		Seed	40.96 ± 0.84^{f}	3.67 ± 0.10^{k}	11.93 ± 0.26^{d}	0.07 ± 0.002^{f}	45.76 ± 0.49^{h}
	Convection oven drying	Peel	7.39 ± 0.05^{k}	5.12 ± 0.02^{f}	6.95 ± 0.07^{f}	0.03 ± 0.02^{f}	80.50 ± 0.06^{c}
		Flesh	$9.44 \pm 0.o9^{j}$	5.50 ± 0.03^{e}	4.56 ± 0.02^{h}	0.03 ± 0.003^{f}	80.47 ± 0.05^{c}
		Seed	4.32 ± 0.07^{n}	3.02 ± 0.11^{l}	19.26 ± 0.29^{c}	0.53 ± 0.02^{a}	72.87 ± 0.41^{f}
	Freeze Drying	Peel	2.63 ± 0.12^{o}	3.63 ± 0.09^{k}	6.97 ± 0.07^{f}	0.32 ± 0.02^{b}	86.45 ± 0.16^{b}
		Flesh	4.91 ± 0.07^{m}	2.96 ± 0.01^{l}	3.08 ± 0.07^{j}	0.06 ± 0.001^{f}	88.99 ± 0.13^{a}
		Seed	4.53 ± 0.27^{n}	4.48 ± 0.05^{h}	20.94 ± 0.65^{b}	0.17 ± 0.01^{e}	69.88 ± 0.81^{g}

a,b,c,d,e,f,g,h,i,j,k,l,m,n,o Means in a column with different superscripts differ significantly ($P<0.05$),. Each value represents the means of three replicates

3.3.5 Commercial Pumpkin Flour

Table 3.2 below show proximate composition of commercial pumpkin flour as provided by Cedenco Foods Ltd.

Table 3-2 : Commercial pumpkin flour (proximate)

Nutrients/Components	Percentage (%) (w/w)
Ash	5.70
Protein	7.10
Fat	3.10
Carbohydrate	82.30
Moisture	1.80

3.3.6 Colour Value of Raw Pumpkin and Pumpkin Flour

Table 3-3 below shows the result of colour value measurements for pumpkin and pumpkin flour. Freeze drying results in lighter colour as measured by *L* values. Each fraction (peel, flesh, seed) from both varieties are significantly different (P<0.05) in terms of *L* and *b* values. However, *a* values are not significantly different (P>0.05) between varieties. Interestingly the flour produced from the flesh of buttercup using freeze drying gave the highest value of *L* (117.13 ± 1.20) which indicates that freeze drying can preserve the colour of the flesh. Flour from buttercup flesh showed the strongest redness (indicated by *a* value) and the weakest was in flour from the raw peel of crown pumpkin. The highest value of *b* is shown in flour made of crown pumpkin using freeze drying (indicated by *b* value = 45.70 ± 0.08). Que et al (2008) found that freeze drying reduced discolouration and produced high quality of pumpkin flours. However, freeze drying is not a commercially viable drying techniques due to cost. According to MacDougall (2002) the colour of a processed product is often expected by the consumer to be as similar as possible to the raw one. Colour in pumpkin is due to the presence of carotenoid pigment. Therefore the colour of the product is an indicator of carotenoid content which is one of the main health benefits of pumpkin. The carotenoid content for the commercial pumpkin flour and final extrudate were measured and these are reported in **section 7.3.1.**

Table 3-3 : Colour Value (*L***a***b**) of raw pumpkin and pumpkin flour (peel, flesh, seed) from two (2) cultivars using different methods of drying

Pumpkin	Processing	Fractions	L	a	b
Crown	Raw	Peel	53.42 ± 0.27^{l}	-0.55 ± 0.36^{e}	24.91 ± 1.61^{f}
		Flesh	67.94 ± 2.69^{g}	12.29 ± 1.79^{b}	42.75 ± 3.36^{b}
		Seed	62.14 ± 0.91^{i}	3.42 ± 1.05^{d}	19.16 ± 1.73^{g}
	Convection Oven Drying	Peel	65.00 ± 0.33^{h}	-4.19 ± 0.24^{f}	29.42 ± 0.50^{e}
		Flesh	75.84 ± 1.07^{f}	5.77 ± 0.44^{c}	37.76 ± 0.55^{c}
		Seed	67.18 ± 0.80^{g}	-0.63 ± 0.49^{e}	22.33 ± 0.27^{g}
	Freeze Drying	Peel	83.79 ± 0.53^{e}	-2.55 ± 0.29^{e}	39.96 ± 0.11^{c}
		Flesh	84.55 ± 0.40^{e}	4.86 ± 0.15^{c}	45.70 ± 0.08^{a}
		Seed	66.40 ± 0.73^{g}	-1.37 ± 0.48^{e}	25.33 ± 1.15^{f}
Buttercup	Raw	Peel	50.58 ± 1.06^{m}	2.35 ± 0.51^{d}	20.66 ± 1.78^{g}
		Flesh	57.85 ± 2.25^{k}	14.03 ± 1.75^{a}	35.13 ± 5.04^{d}
		Seed	60.05 ± 1.12^{j}	3.00 ± 0.38^{d}	21.69 ± 0.91^{g}
	Convection Oven drying	Peel	94.40 ± 1.38^{c}	0.22 ± 0.03^{e}	2.20 ± 0.15^{c}
		Flesh	109.92 ± 0.47^{b}	2.88 ± 0.12^{d}	10.65 ± 0.39^{h}
		Seed	91.49 ± 0.85^{d}	3.42 ± 0.17^{d}	-1.54 ± 0.93^{j}
	Freeze Drying	Peel	108.99 ± 0.66^{b}	-10.93 ± 0.29^{g}	-1.77 ± 0.27^{j}
		Flesh	117.13 ± 1.20^{a}	-2.54 ± 0.23^{e}	10.95 ± 1.42^{h}
		Seed	91.09 ± 0.05^{d}	-1.72 ± 0.29^{e}	-1.56 ± 0.52^{j}

*a, b,c,d,e,f,g,h,I,j,k,l,m Means in a column with different superscripts differ significantly ($P<0.05$)

While, colour values of pumpkin flour supplied by Cedenco Foods Ltd are as follows; *L value* 76.86, *a value* +2.07 and *b value* +33.84.

3.4 Conclusion

These results show that pumpkin flour can be produced from three (3) fractions (peel, flesh and seed) of pumpkin. Pumpkin flour from the flesh of the pumpkin were found to have similar properties to the commercial pumpkin flour in terms of proximate compositions and colour values.

Chapter 4: Preliminary Extrusion Processing of Pumpkin-Corn Grits Expanded Snacks

4.1 Introduction

The purpose of these preliminary extrusion processing experiments was to determine the feasibility of extruding pumpkin flour with corn grits and to determine suitable extrusion conditions for producing the expanded snack products.

4.2 Materials and Methods

4.2.1 Extrusion Process

Extruded expanded snacks were made from three (3) different fractions (peel, flesh and seed) of crown pumpkin flour (convection oven) with corn grits (spec 220, supplied by Corson Grain Ltd, Gisborne, New Zealand). Material was extruded using a twin-screw extruder (Clextral BC21 twin-screw co-rotating, self wiping extruder, Clextral, Firminy Cedex, France). Basic recipes and extrusion conditions were used as described by Brennan et al. (2008).

4.2.2 Basic Recipes for Expanded Snack Product

Pumpkin flour from three different fractions (peel, flesh, seed) was used as a trial. The formulations are shown in the **Table 4-1** below.

Table 4-1 : Basic recipes for extruding pumpkin with corn grit (Brennan et al., 2008)

Sample	Pumpkin Flour (g)	Corn Grits (g)
Control	0	1000
Peel	100	900
	300	700
	500	500
Flesh	100	900
	300	700
	500	500
Seed	100	900
	300	700
	500	500

4.2.3 Extrusion Conditions

Table 4-2 below shows the extrusion conditions. The torque, pressure thrust, pressure die, power consumption and die temperature were recorded when stable during the extrusion process.

Table 4-2 : Extrusion conditions (Brennan et al., 2008)

Parameter	
Internal barrel width	46 mm
Height	25 mm
Screw Diameter	24.7 mm
Temperature of the barrel	40ºC,60ºC,80ºC,100ºC,140ºC, 160ºC and 180ºC
Screw speed	315 rpm
Feed rate	6.75 kg/h
Water rate	0.29 L/h
Die diameter	3 mm
Screw Configuration	A: Forward, 13mm pitch, 50mm length B: Forward, 10mm pitch, 50mm length C: Forward, 7mm pitch, 50mm length D: Forward, 7mm pitch, 25mm length
Cutter set	200 rpm

4.2.4 Product Characteristics

4.2.4.1 Colour Measurement

Colour measurements of samples were carried as described in **section 3.2.4.**

4.2.4.2 Expansion Ratio

Expansion ratio (%) is measured as the radial expansion calculated as the ratio of the diameter of the extruded snack to die diameter multiplied by 100. The diameter of 20 extruded snack pellets was taken at random from each product made and were measured with a digital caliper (Mitutoyo: Tokyo, Japan) and the average diameter recorded.

Percentage expansion of the samples was determined using the formula (1) below:

$$Percentage\ Expansion\ (\%) = \frac{Average\ cereal\ extrudate\ diameter}{Diameter\ of\ die} \times 100 \ldots\ldots (1)$$

4.2.4.3 Product Density

Bulk Density (kg/L) was measured from the weight of a standard volume of product and **True Density** was determined from the weight of the extrusions and the volume of poppy seeds displaced. The method is described by Brennan, M.A., Merts, Monro, Woolnough and Brennan,C.S(2008). Bulk density and true density were calculated using equations (2) and (3) respectively as shown below:

$$Bulk\ Density = \frac{Weight\ of\ extruded\ products\ (kg)}{Volume\ of\ container\ (L)} \quad \text{…………………… (2)}$$

$$True\ Density = \frac{Weight\ of\ extruded\ products\ (kg)}{Volume\ of\ container\ (L) - Volume\ of\ poppy\ seed\ (L)} \quad \text{……………………(3)}$$

4.2.4.4 Product Texture

Hardness was measured using an Instron Universal testing machine (Instron model 4502 with a 1KN load cell) fitted with a Kramer Shear cell. The Kramer cell had a lower fixed cell of 67 × 64 × 50 mm and an upper moving component fitted with three blades each 125 × 70 × 3 mm. Before measuring hardness, the samples were dried overnight in a forced air oven at 35ºC to achieve a water activity (Aw) of 0.2-0.4. The lower cell was filled to 40mm depth with the extruded snacks and the test begun. The crosshead speed of the blades was 180mm/min with a compression limit of 50mm. The test was carried out at room temperature (25°C). Hardness was determined as the force recorded as the probe moved through the sample and transitioned from compression packing to crushing. An example of this is given (**Figure 4-1)** which shows the relationship between force and vertical distance. Triplicates of each sample were measured and the average was calculated.

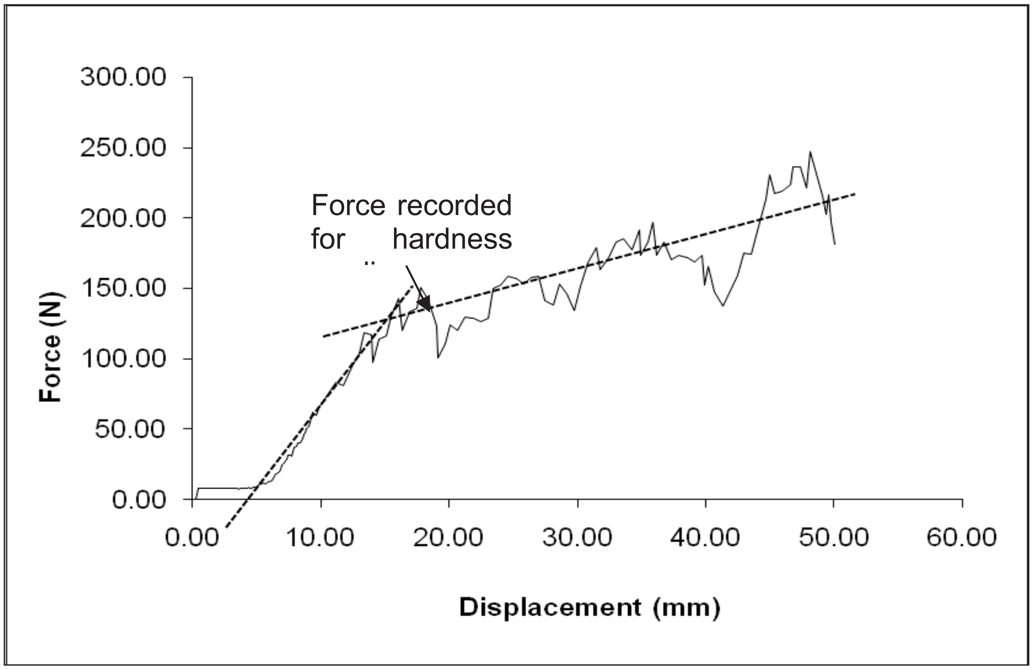


Figure 4-1: Displacement (mm) versus Force (N) for 100% corn grits extruded product at 250rpm

4.3 Results and Discussion

In providing a potential means towards healthy snack production, pumpkin flour was found to be a potential ingredient that might improve the nutritional value of a snack but the literature also indicated that pumpkin flour might affect the extrusion conditions as well as the final product quality. Therefore, this preliminary extrusion experiment was conducted to determine suitable extrusion conditions and identify whether pumpkin flour could be used as an ingredient of an expanded snack product. However, pumpkin flour is low in starch content (7%) and needs to be incorporated with other starch based ingredients for extrusion processing. Common starch based ingredients that are used for extrusion processing are cereals and potato derivatives, wheat flour, maize and rice. In this study, maize or corn grits were selected to be incorporated with pumpkin flour as they have a significant function and ability to produce a well expanded snack with a high expansion ratio, low bulk density and low hardness allowing the snack to be readily chewed (Huang & Rooney, 2001).

In producing pumpkin based expanded snacks, three different fractions from crown pumpkin flour (convection oven) were incorporated with corn grits (spec 220) at levels of 10%, 30% and 50%. Corn grits (100%) were used as a control. Then a physical analysis was carried out to determine product colour, product density, expansion ratio and hardness.

4.3.1 Extrusion Parameters for the Expanded Snack Product

Pumpkin has been processed in a number of ways but little detailed information is available on extrusion parameters used to produce extruded pumpkin based snack products. As suggested by Meng, Threinen, Hansen and Driedger.,(2010) and Ravindran, Carr and Hardacre., (2011), the desired characteristics of expanded snack products that should be targeted and achieved include well expanded, high expansion ratio, low bulk density and low hardness. Other desired characteristics were large air cells and thin cell walls. These can be achieved through extrusion processing at low feed moisture, high screw speed and medium to high barrel temperature (Pansawat et al., 2008). These parameters are investigated in this chapter. As a starting point, the settings for these parameters were based on Brennan et al.,(2008), who used an identical extruder to the one in this study. Additionally the product of Brennan was predominantly based on corn grits.

The effect of extruding pumpkin flour with corn grits on torque, thrust pressure, die pressure, temperature at the die face and power consumption are presented in **Table 4-3.** Results show that incorporating pumpkin flour from different fractions with corn grits at different percentage levels reduces torque, thrust pressure and die pressure with the exception of 10% peel and 30% seed.

In extrusion processing, torque is referred to as the amount of energy that has been absorbed by the raw material due to the shear exerted by screws (Fichtali & Van De Voort., 1989). The value of torque provides an indicator for steady state running of the extrusion. In this study, each formulation gave a different value of torque as compared to the control. Under constant extrusion conditions (feed rate, screw speed and barrel temperature), torque was reduced to the lowest (51%) when flesh pumpkin flour was incorporated with corn grits compared to the control. Increased use of pumpkin flour likely decreased the torque value due the presence of sugar, pectin and fibre in the pumpkin flour. It has been reported by Pansawat et al., (2008) that these components decrease the resistance against the melt viscosity.

Pressure thrust ranged from 40-69 bar. The highest pressure thrust was observed at 30% pumpkin flour from peel and 50% pumpkin flour from seed, which is 6% higher than the control.

Table 4-3 : Processing parameters of control and pumpkin flour mixed with corn grits at different percentage levels to produce expanded snacks.

Sample	Torque (Nm)	Pressure Thrust (Bar)	Pressure Die (Bar)	Temperature at the die face (°C)	Power Consumption (kw)
Control (100% Corn Grits)	5.3	65	92	126.4	1.45
10% Peel (Crown Pumpkin-Convection oven) with 90% Corn Grits	4.5	69	98	129.6	1.26
30% Peel (Crown Pumpkin-Convection oven) with 70% Corn Grits	3.6	54	76	129.7	0.98
50% Peel (Crown Pumpkin-Convection oven) with 50% Corn Grits	3.2	51	74	129.9	0.60
10% Flesh (Crown Pumpkin-Convection oven) with 90% Corn Grits	4.1	68	90	128.2	1.24
30% Flesh (Crown Pumpkin-Convection oven) with 70% Corn Grits	2.8	40	64	128.8	0.76
50% Flesh (Crown Pumpkin-Convection oven) with 50% Corn Grits	2.6	40	64	131.2	0.72
10% Seed (Crown Pumpkin-Convection oven) with 90% Corn Grits	4.1	66	90	130.4	1.10
30% Seed (Crown Pumpkin-Convection oven) with 90% Corn Grits	3.8	68	103	131.1	0.94
50% Seed (Crown Pumpkin-Convection oven) with 90% Corn Grits	3.2	69	94	129.9	0.94

4.3.2 Product Characteristics

4.3.2.1 Colour Value of Expanded Snack Products of Pumpkin Flour mixed with Corn Grits

In this study the colour value of snacks containing all fractions (except peel) were found to be increased. The darkness increased, as reflected by a decrease in L value. This result is similar to Altan et al. (2008). In particular this result is due to the Maillard reaction and the destruction of heat sensitive pigments. Colour is an important characteristic of extruded foods. Altan, McCarthy and Maskan (2008) stated that colour gave information on the browning reaction that is produced by sugar. **Table 4-4** shows the colour measurement of pumpkin based cereal products with corn grit at different percentage levels.

Table 4-4 : Colour value (*L*a*b**) of expanded snacks made of pumpkin flour (peel, flesh and seed) with corn grits at different percentage levels.

Sample	Formulation	L	a	b
Corn Grits (Control)	100% Corn Grits	94.76 ± 0.70[a]	4.89 ± 0.06[g]	-2.04 ± 1.12[a]
Crown/Convection oven	10%Peel : 90% Corn Grits	78.52 ± 1.14[e]	9.69 ± 0.25[d]	-7.77 ± 0.28[e]
	30% Peel : 70% Corn Grits	73.65 ± 0.19[g]	7.57 ± 0.09[f]	-7.07 ± 0.36[e]
	50% Peel : 50% Corn Grits	71.56 ± 0.56[h]	8.21 ± 0.08[e]	-8.22 ± 0.57[e]
	10%Flesh : 90% Corn Grits	86.85 ± 0.02[b]	10.95 ± 0.12[c]	-4.15 ± 0.28[c]
	30% Flesh : 70% Corn Grits	75.96 ± 0.35[f]	14.97 ± 0.13[a]	-5.91 ± 0.25[d]
	50% Flesh: 50% Corn Grits	70.41 ± 0.17[i]	15.29 ± 0.29[a]	-3.00 ± 0.58[b]
	10%Seed : 90% Corn Grits	82.61 ± 0.26[c]	7.60 ± 0.27[f]	-7.49 ± 0.95[e]
	30% Seed : 70% Corn Grits	81.21 ± 1.29[d]	8.32 ± 0.60[e]	-9.08 ± 0.98[e]
	50% Seed : 50% Corn Grist	75.60 ± 0.88[f]	11.45 ± 0.27[b]	-10.44 ± 0.45[f]

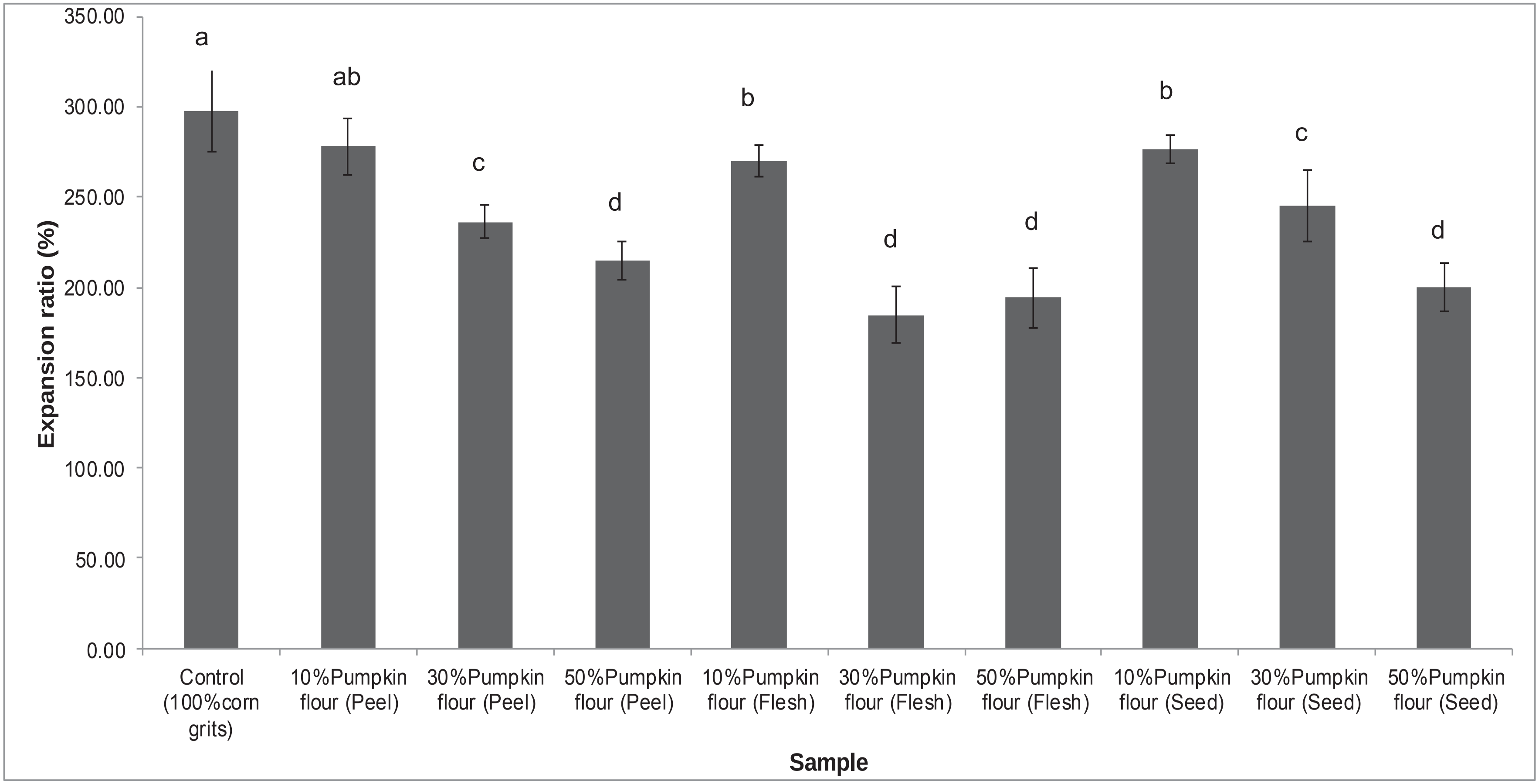
a,b,c,d,e,f,g,h,i Means in a column with different superscripts differ significantly ($P<0.05$). Each value represents the means of three replicates.

4.3.2.2 Expansion Ratio of Expanded Snack Products of Pumpkin Flour with Corn Grits

The expansion property of extruded snacks made from different fractions of pumpkin flour (peel, flesh and seed)) with corn grits at different percentage levels are shown in **Figure 4-2**. According to Ilo, Tomschik, Berghofer and Mundigler (1996) the expansion ratios of extruded products are dependent on moisture content, product temperature and feed rate. Furthermore the degree of expansion determines the extruded product's structure.

As can be seen in **Figure 4-2** an increasing percentage of pumpkin flour from all fractions, decreased the product diameter thus resulting in a decrease in the expansion ratio. Colonna, Tayler and Mercier (1989) reported that the decrease in expansion at higher temperatures is due to the increase of dextrinisation and the weakening of structure. The expansion ratio of all pumpkin fractions flour with corn grits at different percentage levels were significantly ($P<0.05$) lower than the control.

Further research needs to be carried out because the quality of extruded product can vary depending on the extrusion parameters e.g. types of extruder, screw configuration, feed moisture, temperature profile in the barrel sections, screw speed and feed rate (Ilo et.al.,1996).

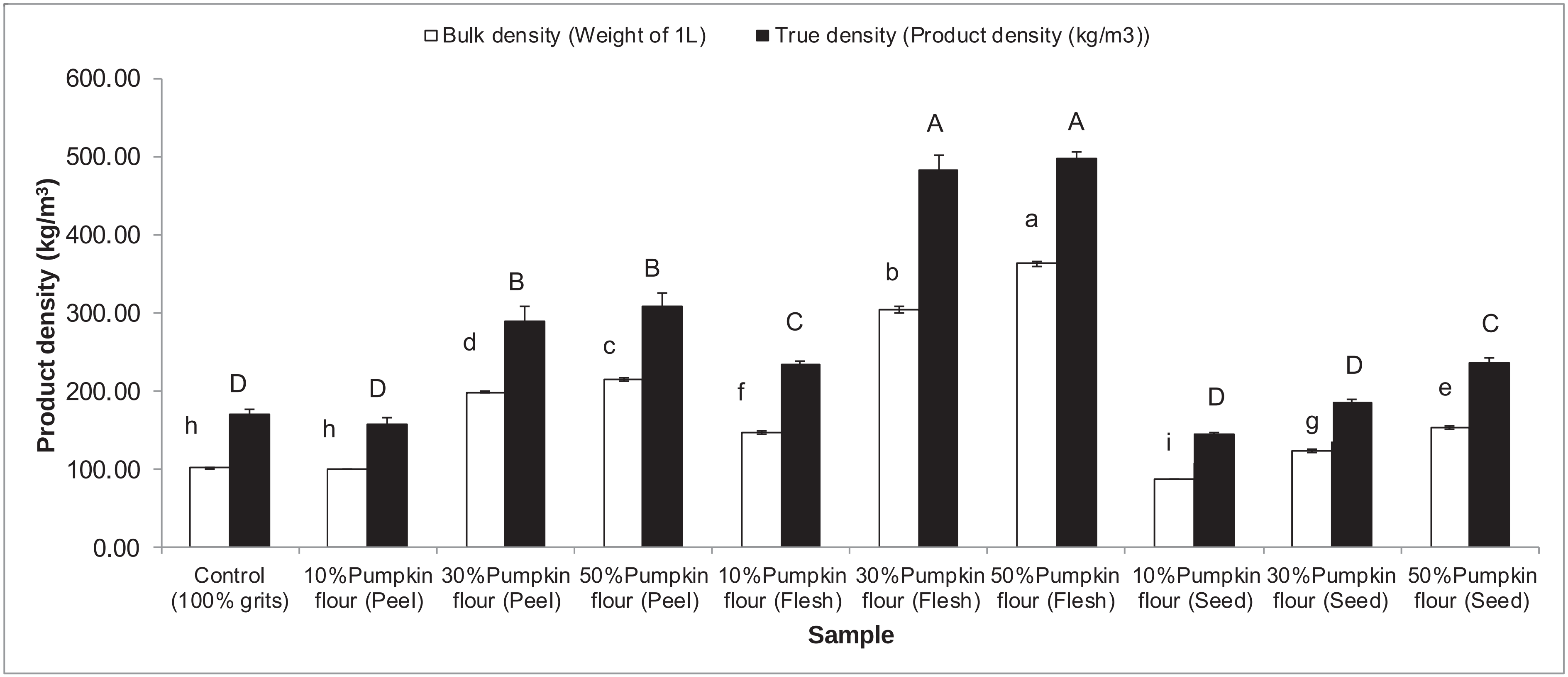


*Error bars represent standard deviation of replicates (values in column with the same letter annotation are not significantly different (P>0.05)

Figure 4-2 : Expansion ratio of the expanded snack

4.3.2.3 Bulk Density of Expanded Snack Products made of Pumpkin Flour and Corn Grits

Figure 4-3 shows the bulk density of expanded snacks made with different percentage levels of pumpkin flour fractions (peel, flesh and seed) with corn grits. The density of extrudates ranges from 140-500kg/m3. The density of extrudates in samples containing 10% pumpkin flour (peel) , 10% pumpkin flour (seed) and 30% pumpkin flour (seed) are not significantly different ($p > 0.05$) from the control. As the level of pumpkin flour increased for all fractions and all percentage levels, the extrudates exhibited higher density. However, increased levels of pumpkin flour have an inverse relationship with the expansion ratio. This result agrees with those previous of studies, which showed that increasing the product density is correlated with decreasing expansion ratio (Ding, Ainsworth, Plunkett, Tucker & Marson., 2006; Foster, 2004).

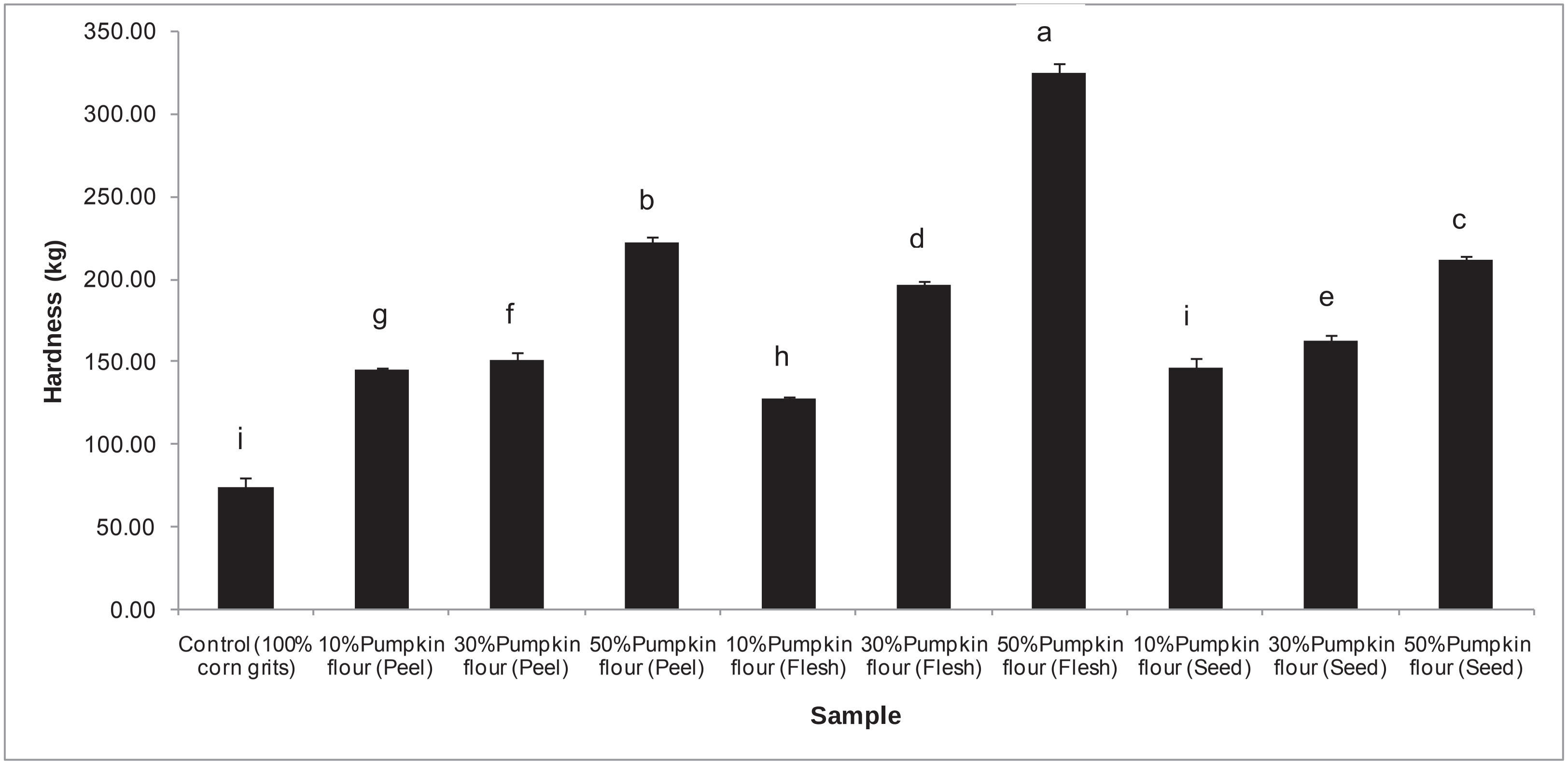


*Error bars represent standard deviation of replicates (values in columns with the same letter annotation are not significantly different (P>0.05)

Figure 4-3 : Product density of the expanded snack

4.3.2.4 Texture of Expanded Snack Products made of Pumpkin Flour with Corn Grits

The texture properties of expanded snacks made with different levels of pumpkin fractions (peel, flesh and seed) with corn grits are shown in **Figure 4-4.** The hardness for all samples was found to be significantly different ($p<0.05$) from the control. The sample containing 10% pumpkin seed flour with 90% corn grits gave a similar texture as the control. The results also show that the expanded snacks containing 50% pumpkin flesh flour with 50% corn grits gave the hardest texture. According to Ryu and Ng (2001), the hardness of extruded products is due to increases of protein or gluten, amylose and water content. Textures of extruded products are dependent on various process variables such as barrel temperature, screw speed and feed rate. Moreover, texture is a critical quality factor for products (Puppala, 1998).



*Error bars represent standard deviation of replicates (values in columns with the same letter annotation are not significantly different (P>0.05)

Figure 4-4 : Hardness of the expanded snack

4.3.3 Expanded Snacks made of Pumpkin Flour mixed with Corn Grits

Figure 4-5, **Figure 4-6** and **Figure 4-7** show an expanded snacks consisting of pumpkin flour from different fractions combined with corn grits at different percentage levels.

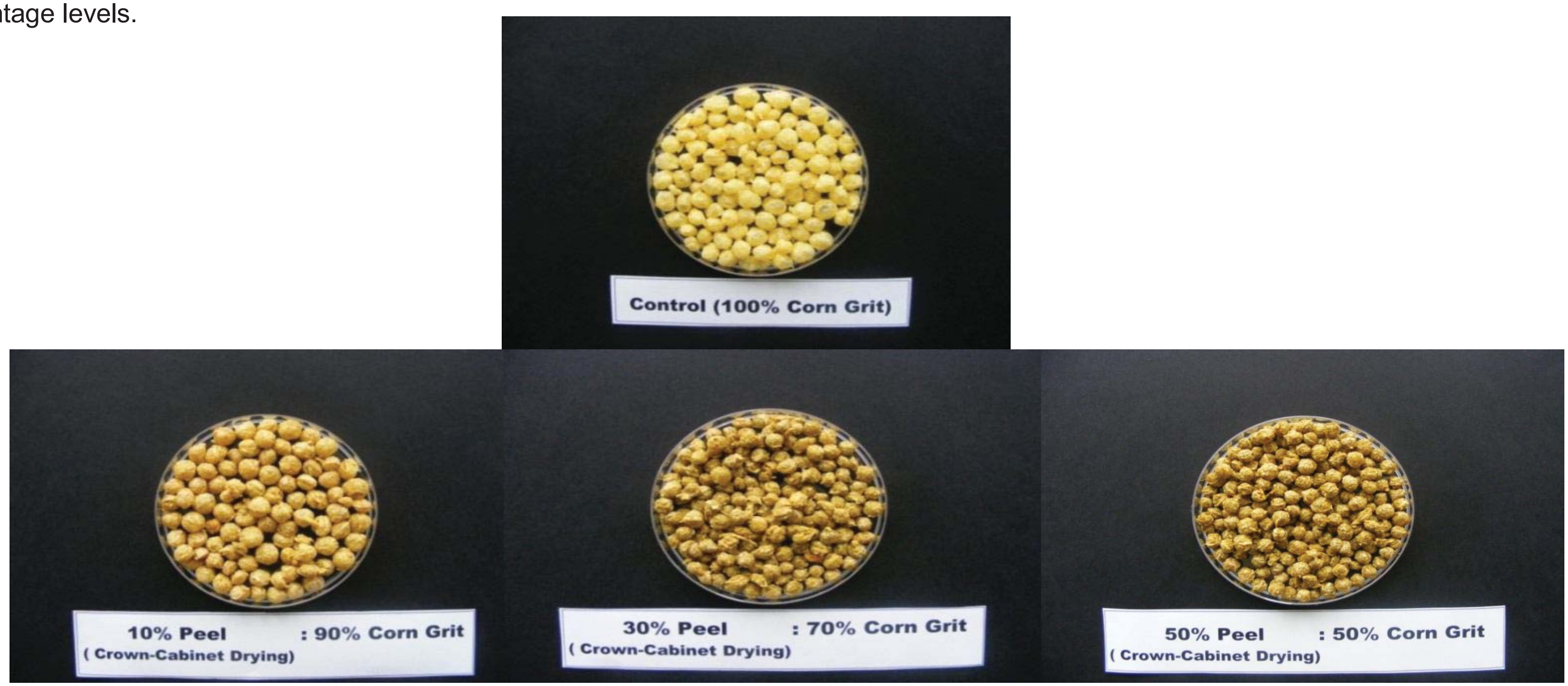


Figure 4-5 : Expanded snacks made from pumpkin flour (peel fractions) with corn grits

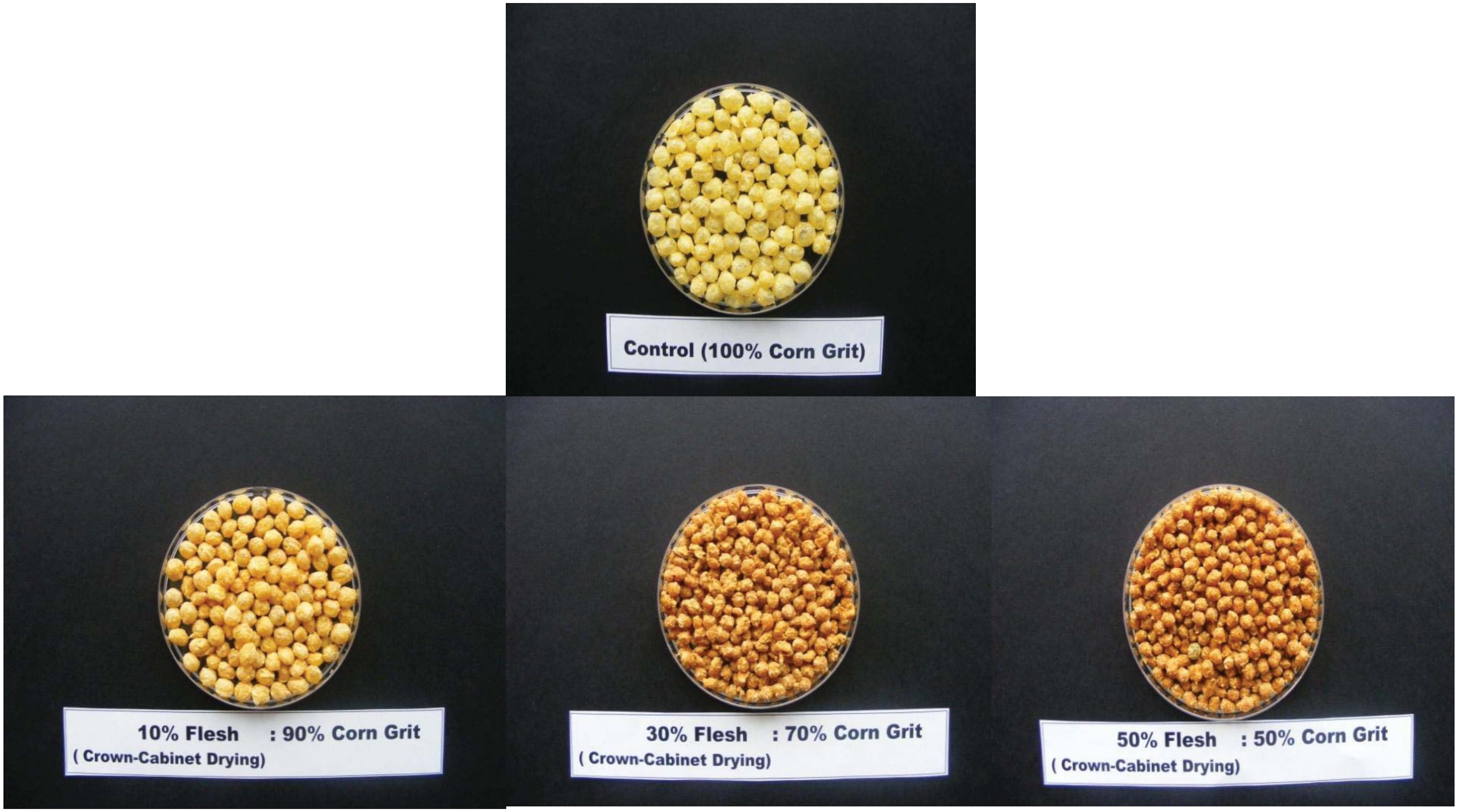


Figure 4-6 : Expanded snacks made from pumpkin flour (flesh fractions) with corn grits

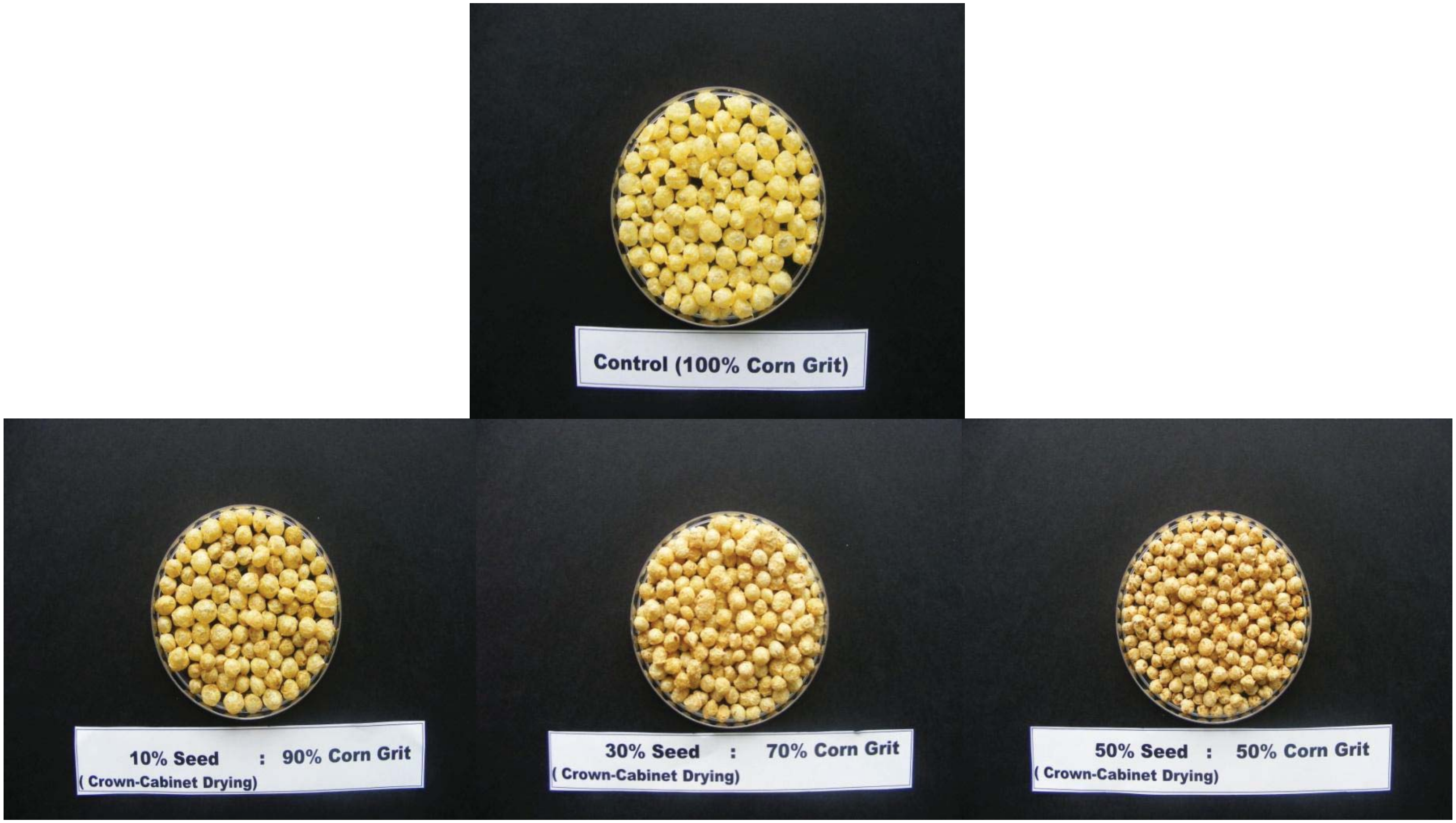


Figure 4-7 : Expanded snacks made from pumpkin flour (seed fractions) with corn grits

As seen in **Figure 4-5**, **Figure 4-6** and **Figure 4-7**, the colour of extrudates of pumpkin flour blended with corn grits became darker as the percentage of pumpkin flour inclusion increased for all fractions. 50% of pumpkin flour in the blend, produced a burnt and unappealing colour in the final products. This could quantified with the *L, a*, and *b* values as described in **section 4.3.2.1.** The results showed that decreased values of *L* were found at higher percentages of pumpkin flour added. This increased the red and yellow colour in the product.

4.3.4 Conclusion

Incorporating pumpkin flour with corn grits at a low percentage level (less than 20%) gives good results in terms of product colour, expansion ratio, bulk density and texture compared to controls.

All samples were found to exhibit higher density as the level of pumpkin flour increased (more than 30%). This result should be avoided as the changes to the product quality are detrimental.

Even though the extrusion parameters based on Brennan et al., (2008) can be applied to pumpkin based expanded snacks this may not achieve the desired characteristics of the product as discussed in the introduction. Therefore several adjustments in terms of extrusion processing conditions need to be made for the subsequent experiments. These conditions are detailed in the following chapter and optimised in **Chapter 6**.

Chapter 5: The effect of varying the proportion of pumpkin flour at two mass flow rates and at two screw speeds on processing parameters and the physical characteristics of the extruded product.

5.1 Introduction

Consumer interest in ready-to-eat (RTE) snack foods is growing due to their convenience, value, attractive appearance, taste and texture (Harper, 1981). Cereal-based extruded snacks are the most commonly consumed snacks (Rhee, Kim, Kim, Jung & Rhee., 2004). Extruders can blend the diverse ingredients used to develop novel snack foods. The quality of the final product depends on the processing conditions used during extrusion and this includes the composition of the raw materials, feed moisture, barrel temperature, screw speed and screw configuration (Yang, Peng, Lui & Lin, 2008). Moreover ingredients and formulation play an important role in developing the texture of the extruded product and ultimately the acceptability of the extruded product to the consumer. Additionally, the conditions under which the product is processed will determine the survivability of labile functional ingredients including vitamins, pigments such as β-carotene and volatile flavour compounds. Therefore, processing must be carefully controlled to optimise the survival of functional components.

Most snack foods contain a high proportion of corn, wheat and rice, with potato and oat and other grain products commonly added in smaller quantities. Vegetable powders are occasionally added but are not common in RTE snacks. Pumpkin is a good source of carotenes with are responsible for the yellow color of the flesh, they also contain appreciable levels of sugar and pectin. Sugar sweetens products that include pumpkin, while pectin is a soluble fibre that delivers many ealth benefits. However, the utilisation of pumpkin has been limited to the consumption of fresh products as a vegetable, or thickeners in soups and purees (Konopacka., et al., 2010) and the production of dry powders that are also used to colour, flavour and thicken a range of foods including soups and purees. A potential avenue of development for pumpkin based products is for the expanded snack market where pumpkin can be used to naturally enhance the flavour and colour of these products. The incorporation of pumpkin flour which naturally contains 37% sugar and 14% pectin (Ptichkina, Markina & Rumyantseva, 2008) into the extruded snack will change the extrusion system, generally making it more difficult to achieve a highly expanded low density snack (Hardacre, pers com). However, the limits for the addition of pumpkin powder and detailed quantitative knowledge of its effects on the physical properties of snacks containing pumpkin powder are unknown. In this study the effect of varying the proportion of pumpkin flour and screw speed on the extrusion parameters and the final quality of extruded product was studied.

5.2 Materials and Methods

5.2.1 Raw Materials

Pumpkin flour (supplied by Cedenco Foods Ltd, Gisborne New Zealand) and Specification 220 corn grits from Corson Grain Ltd, Gisborne, New Zealand were used. The proximate composition of corn grits and pumpkin flour, according to manufacturers data are presented in **Table 5-1** below.

Table 5-1: Proximate composition of raw materials (corn grits and pumpkin flour) used for the extrusion.

Proximate	Corn grits	Pumpkin Flour
Protein (%)	6.0-9.0 maximum	7.10
Fat (%)	1.5 maximum	3.10
Moisture (%)	10-14	1.80
Ash (%)	2.0	5.70
Carbohydrate (%)	80.5	82.30

5.2.2 Pasting Properties (RVA)

The main objective of the Rapid Visco Analysis (RVA) in this chapter was to determine the viscosity of pumpkin flour at different concentrations. Pasting properties of the pumpkin flours were determined using a Rapid-Visco Analyser (Rapid Visco Analyser Series S4A, Warriewood, Australia) equipped with Thermocline software. The method used was according to the manufacturer's instructions using set standard 1. Each RVA canister contains 3g of samples (ground and sieved to 200um) and was made up to 27 g using distilled water. The samples were grounded and sieved in order to ensure that no thermal degradation of the starch occurs and to obtain a uniform size distribution during RVA analysis (Paton & Spratt, 1981). The RVA parameters are as follows; peak viscosity, peak time, pasting temperature, peak temperature, holding strength, breakdown, final viscosity, setback 1 and setback 2. These were recorded as shown in **Figure 5-1** below. All RVA parameters mentioned above were used to describe the pasting properties of the materials. Each analysis was performed in triplicate.

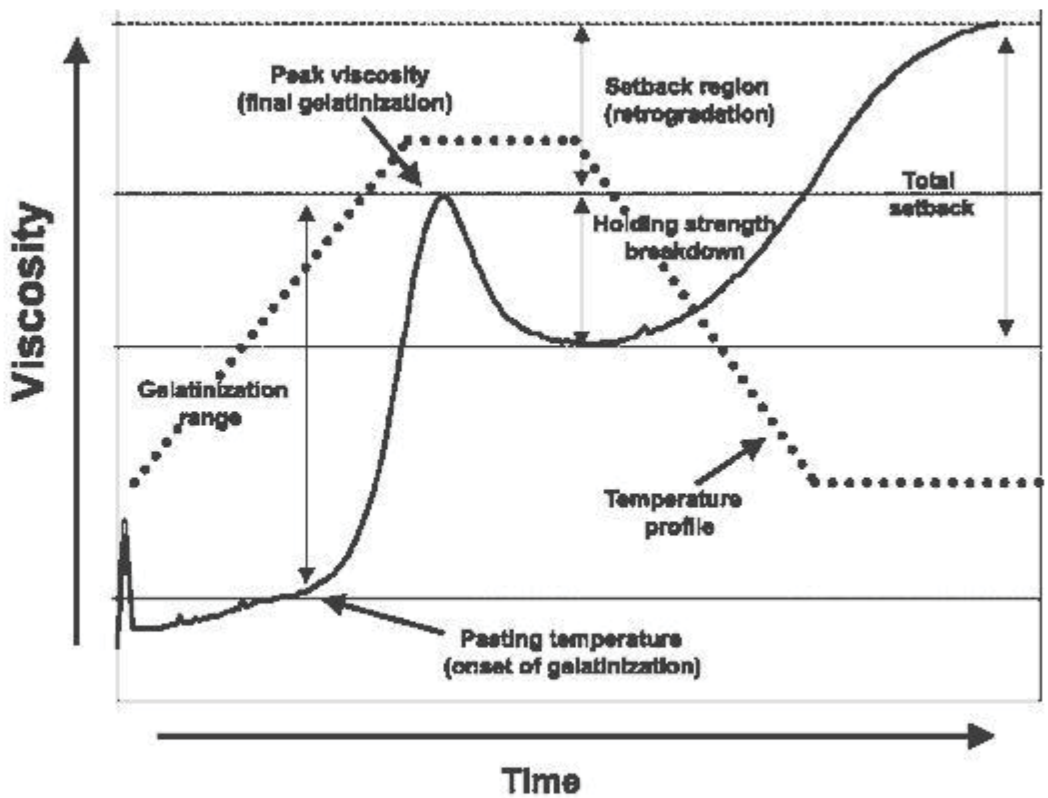


Figure 5-1 : A typical complete RVA curve (Paton & Spratt,1981**)**

5.2.3 Extrusion Processing

5.2.3.1 Extrusion at constant screw speed with two mass flow rate

Expanded snack products were made by extruding finely milled corn endosperm (grits) as a control (100%) and corn grits mixed with pumpkin flour added at 5%, 10% and 20% on a dry weight basis using a twin- screw extruder (Clextral BC21 twin-screw co-rotating self wiping extruder, Clextral, Firminy Cedex, France). Basic recipes and extrusion conditions were used as described in Brennan et al., (2008). Two feed rates of 7.5 and 8.5 kg/hr for each formulation were used. The torque (Nm), power consumption (kw), specific mechanical energy (SME, kWhr/kg), expansion ratio, true density and hardness were measured.

5.2.3.2 Extrusion at Two Screw Speeds with Constant Mass Flow Rate

Expanded snack products were made by extruding finely milled corn endosperm (Specification 220 corn grits) as a control (100%) and corn grits mixed with pumpkin flour added at 5%, 10%, 15% and 20% on a dry weight basis. These ingredients were added into the extruder at a constant mass flow rate of 12.5kg/hr. Processing was carried out using a twin- screw extruder (Clextral BC21 twin-screw extruder, Clextral, Firminy Cedex, France). The barrel length was 700mm and the screw diameter was 24.7mm. The screw configuration (**Figure 5.2**) was a four pairs of 13mm forward pitch screws each 50mm in length, five pairs of, 10mm forward pitch screws each 50mm in length, and five pairs of 13mm forward pitch screws each 50mm in length. The barrel temperatures in each section of the extruder from inlet port to die were set at 40°C, 60°C, 80°C, 100°C, 140°C, 160°C and 180°C. A single die with a 3.4mm diameter aperture was used and a knife rotating at 55 rpm cut the emerging product into pellets about 15m in length. Two screw speeds of 250 rpm and 350 rpm were used for each formulation.

During this work the processing parameters for the extruder were recorded; these included torque, electrical energy consumption (kW) and from the energy consumption and the total mass through-put, the specific mechanical energy (SME) was calculated as kWh/kg.

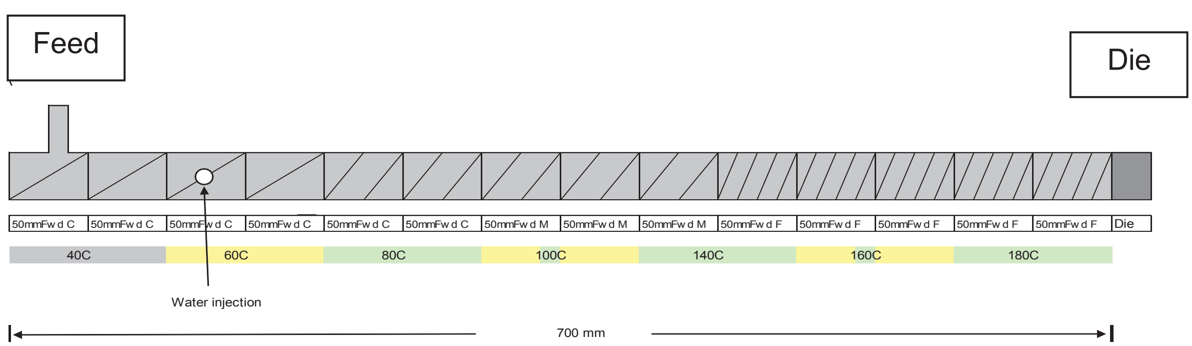


Figure 5-2: Schematic diagram of screw configuration of the extruder, the angle on the schematic represent screw pitch from the feed at the left hand side to the die on the right hand side.

5.2.4 Physical Characteristics

The physical characteristics of the extruded products were measured including: expansion ratio, product density and hardness. The measurement is as described in **4.2.4** .

5.2.5 Texture Analysis of Product Mapping

Texture mapping of commercial snack products and pumpkin flour-corn grits expanded snacks was performed in order to compare the crispiness and hardness between the snack products. The plot of a commercial product is used as a benchmark and guidance for pumpkin flour-corn grit snack extrusion processing in order to get the desired texture known to be accepted by consumers.

Several commercial snack products were randomly purchased from Countdown, Palmerston North. The commercial snacks were; ETA skof (burgers), ETA skof (munchos), ETA skof (sonics), ETA skof (balls), Bluebird (burger rings), Bluebird twisties (ottawa) and Pams(twisties).

Pumpkin flour-corn grits expanded snack products were prepared as described in **5.2.3.2.**

The texture analysis for commercial and pumpkin-corn grits snack products was performed using a compression test on the Texture analyser (TA.XT PLUS, Canners Machinery Ltd. Simcoe, Ontario Canada). A probe type of 30mm square, Ottawa cell with a solid base plate (Instron Corporation, Canton, Massachusetts 02021, USA) was used. The compression was done with a 50kg load size and a standard bulk volume of 360 cm^3 of each sample was measured. The test was done under Pre-test speed: 0.5 mm/s, Test speed: 0.5 mm/s, Post-test speed: 10 mm/s, Distance: 50 mm, and Trigger force: 0.1 N. Hardness was determined as the maximum peak force and crispness as the number of positive peaks with threshold set at 0.1 N, as shown in **Figure 5-3.** Measurements were conducted in duplicate.

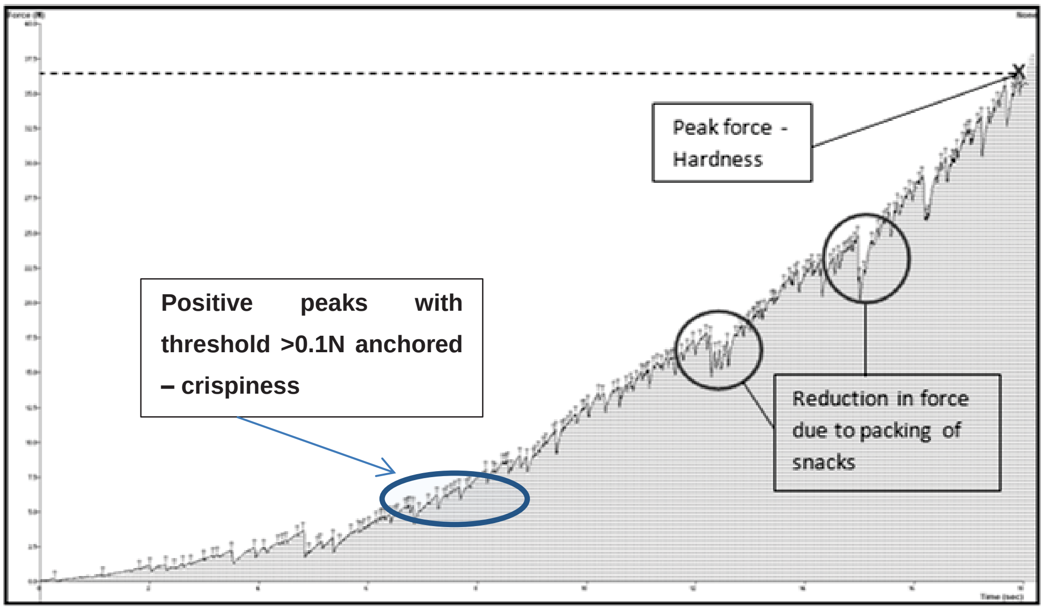


Figure 5-3 : Compression graph of force (N) against time (s)

5.2.6 Statistical Analysis

The experimental data was analysed as described in **3.2.5**.

5.3 Results and Discussion

In this chapter, pasting properties of pumpkin flour starch and comparison of texture between pumpkin-corn grits snacks with commercial snacks are discussed. The effects of adding different proportions of pumpkin flour and operating the extruder at different mass flow rates and screw speeds on the extrusion parameters of torque, specific mechanical energy (SME), power consumption (kW), pressure thrust (bar) and the physical characteristics of extruded products is reported. These include expansion ratio, bulk density, true density and hardness.

5.3.1 Pasting Properties of Raw Ingredients (pumpkin flour-Cedenco)

The main purpose of this experiment was to characterise the pasting properties of pumpkin flour starch, which could be useful in providing the initial guidelines for extrusion food processing and other food processing. It also can be used as a reference for manufacturers in bakery products, soups, sauces, instant noodles, thickeners, colouring agents as well as for flour mixes.

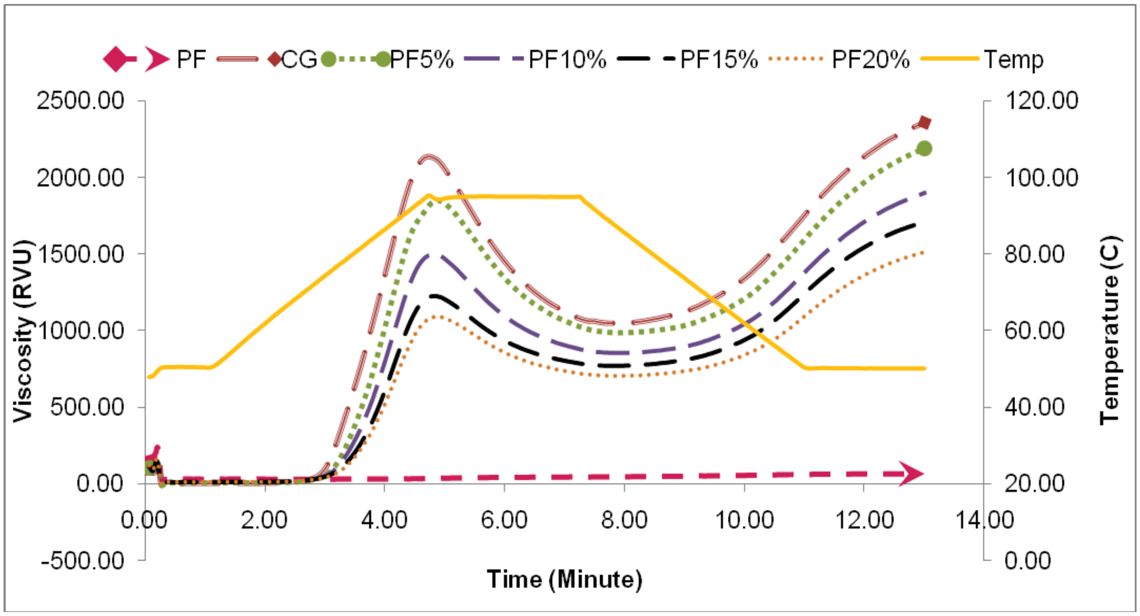


Figure 5-4 : RVA pasting curves of starches in corn grits, pumpkin flour and their blend

Pasting profiles of raw ingredients are presented in **Figure 5-4.** The presence of starch in raw materials plays an important role in extrusion, affecting the organoleptic properties of the final extruded products. Knowing the pasting properties, could help in optimising formulation and extrusion conditions. All samples showed the same pattern for the pasting curve profile with the exception of pumpkin flour, which exhibited no viscosity peak, which may be due to low starch content. This can clearly been seen in **Figure 5-5** below. Low starch content in pumpkin flour (7%) is reflected in the pasting properties of this flour, moreover the interaction between other components such as sugar and pectin that degrade the starch content in the pumpkin flour. Therefore an exponential relationship was shown in the graph based on the hot peak viscosity. Peak viscosity is often correlated with the final product quality, it also provides an indicator of the viscous load likely to be encountered during mixing and processing.

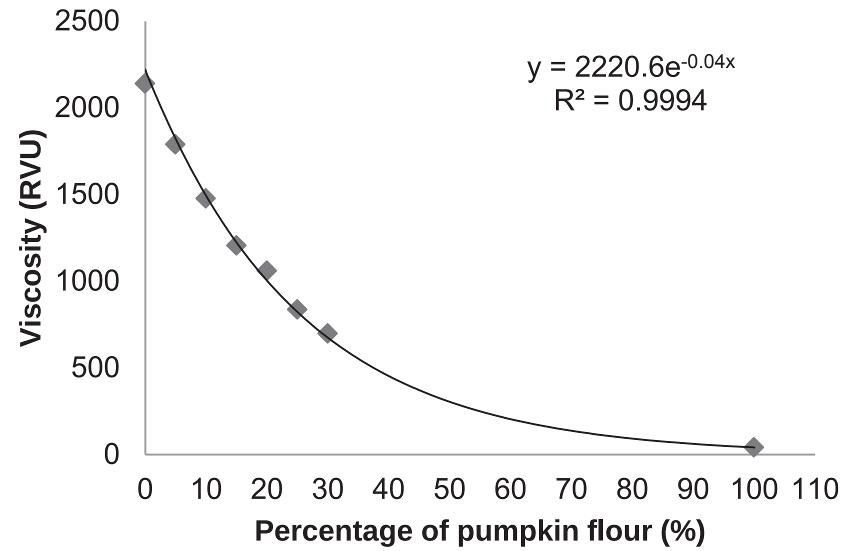


Figure 5-5 : Relationship between percentage of pumpkin flour and hot peak viscosity

This is supported by Bailey et al. (1990) who found only 7% starch content per 100g of pumpkin. Overall, as the level of pumpkin flour increases, both the pasting temperature and peak viscosity decrease. The highest peak viscosity was shown by the control sample (100% corn grits) at 2116.00 RVU, while the lowest peak viscosity was exhibited by the sample mixture of 80%corn grits + 20% pumpkin flour. Variation in peak viscosity was contributed to by the size of starch granules as well as the level of phosphorus present (Singh, Kaur, & McCarthy, 2007). Samples with higher peak viscosity may contain larger starch granules and higher levels of phosphorus. The lower setback was found in the sample mixture of 80% Corn grits + 20% pumpkin flour. This may have resulted in less expanded extrudate as it could lower the retrogradation or aggregation of amylose. Substitution of 5-15% of pumpkin flour achieved peak viscosity in the lowest temperature range of 68.53ºC – 65.27ºC, this requires less energy to cook and produced a stable paste for the extrusion process.

5.3.2 Extrusion at Constant Screw Speed with Two Mass Flow Rate

Pumpkins are mainly eaten by themselves in a cooked state but are also often used as a base for other foods including jams and soups. They are an excellent source of vitamin A (Wien, 1997). The versatility and profitability of the pumpkin crop could be enhanced by diversifying crop use and utilising waste streams. Experience has shown that extrusion technology can be used to make tasty, nutritious snacks or breakfast cereals from pumpkin flour when blended with corn-grits. However, the main constraint in producing extruded products containing high levels of pumpkin flour are the high levels of sugar typically around 37%. High sugar levels interfere with the starch hydration and development of shear in the extruder resulting in reduced expansion and a product that is unacceptably hard (Faller et al., 1999). Therefore, it has become a challenge to determine the optimum process parameters needed to obtain the desired product characteristics (well expanded, low bulk density and acceptable to the consumer) while maximising the throughput rate.

The effect of process parameters and formulation on the physical characteristics of expanded extruded snacks made from pumpkin and corn was discussed in Chapter 4. The results showed that as feed rate and percentage of pumpkin flour increased, the SME decreased. At the same time, torque and power consumption increased as the expansion ratio increased as feed rate and percentage of pumpkin flour increased. However, true density and hardness were decreased for each formulation up to 15% added pumpkin flour.

These results are shown in **Table 5-2**, **Figure 5-6**, **Figure 5-7** and **Figure 5-8** below.

Table 5-2 : Effect of formulations and feed rates on operating conditions of expanded snacks made from pumpkin flour-corn grits

Sample	Mass Flow (kg/hr)	Kw	Torque (Nm)	(SME) kW.hr/kg
Control (100% corn grits)	7.5	1.46[b]	6.60[a]	0.24[a]
	8.5	1.02[f]	3.80[e]	0.15[c]
5% pumpkin flour + 95% corn grits	7.5	1.27[c]	5.30[b]	0.22[b]
	8.5	1.46[a]	5.30[b]	0.20[b]
10% pumpkin flour + 90% corn grits	7.5	1.11[e]	4.30[d]	0.12[d]
	8.5	1.27[d]	4.70[c]	0.20[b]
20% pumpkin flour + 80% corn grits	7.5	0.92[h]	3.70[e]	0.17[c]
	8.5	0.96[g]	3.25[f]	0.16[c]

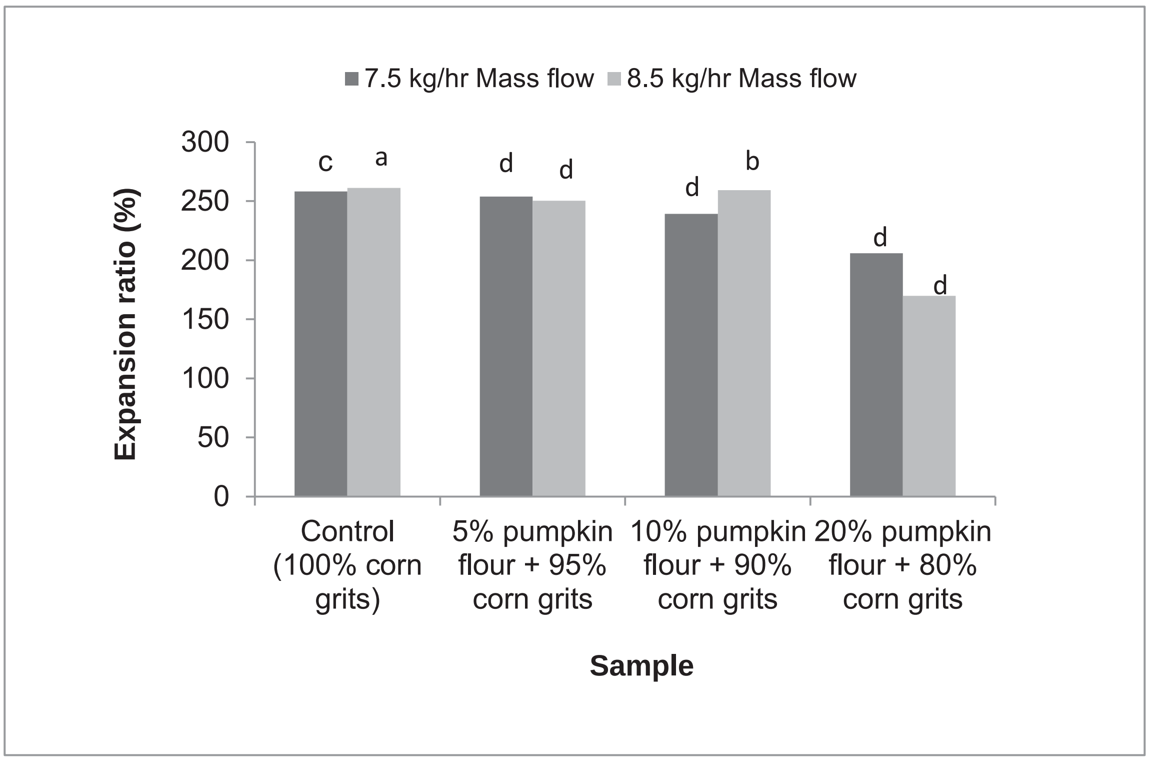


Figure 5-6 : Effect of formulations and feed rates on expansion ratio of expanded snacks made from pumpkin flour-corn grits

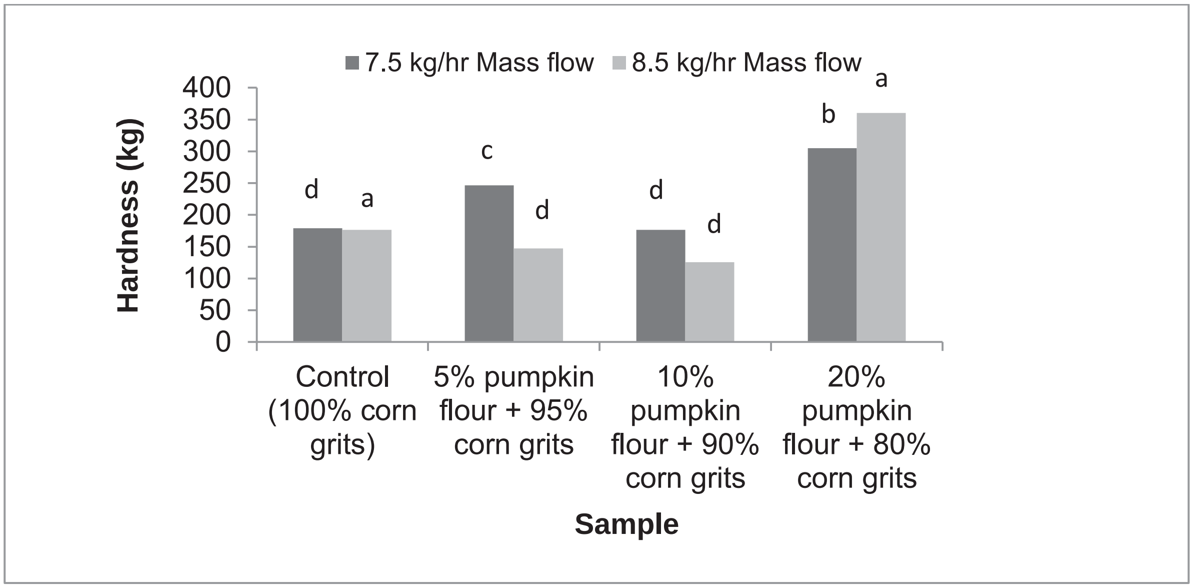


Figure 5-7: Effect of formulations and feed rates on hardness (kg) of expanded snacks made from pumpkin flour-corn grits

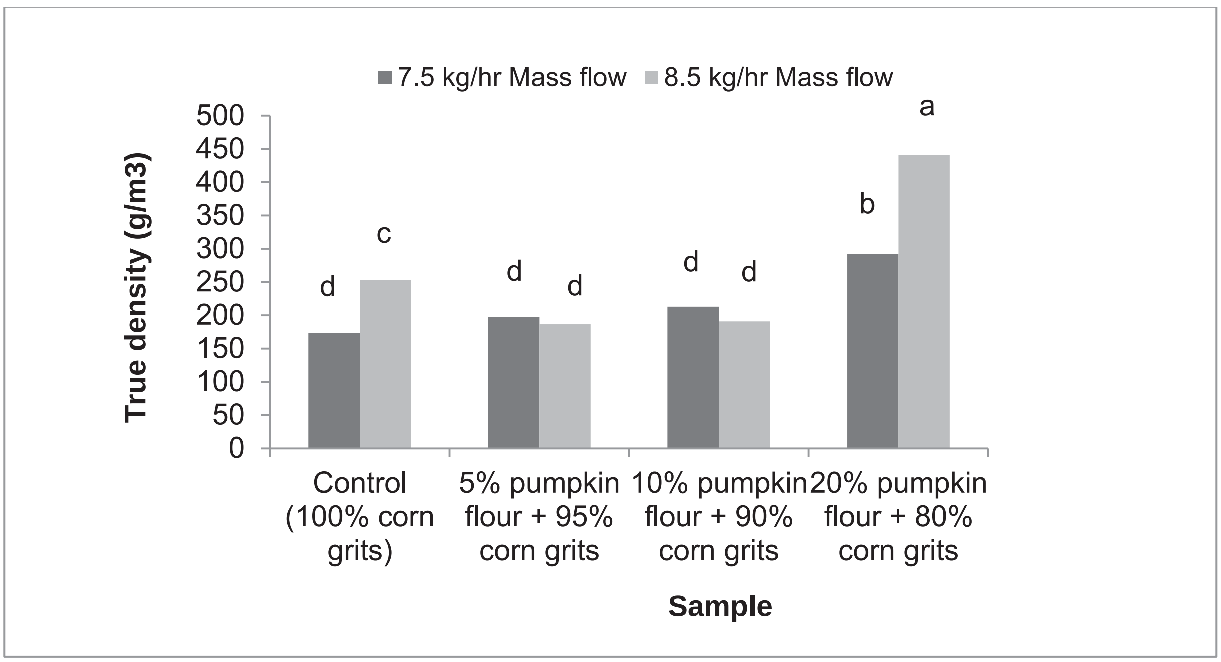


Figure 5-8 : Effect of formulations and feed rates on true density (g/m3) of expanded snacks made from pumpkin flour-corn grits

Table 5-3 : Pearson's correlation

	Sample	Flow rate	kW	Torque	SME	Expansion	Hardness	TD
Sample	1							
Flow rate	0.22	1.00						
kW	-0.59	-0.03	1.00					
Torque	-0.71	-0.35	0.92	1.00				
SME	-0.44	-0.14	0.74	0.80	1.00			
Expansion	-0.79	-0.07	0.65	0.66	0.38	1.00		
Hardness	0.33	0.24	-0.26	-0.30	-0.06	-0.59	1.00	
TD	0.68	0.30	-0.75	-0.78	-0.45	-0.92	0.70	1.00

Increasing pumpkin flour significantly ($P<0.05$) decreased power consumption, SME and torque while increasing product density and hardness. High quality product was produced at all feed rates providing pumpkin flour was incorporated at less than 20%.Therefore formulation and to a lesser extent feed rate, are important in determining the characteristics of the final product.

5.3.3 Extrusion at Two Screw Speeds with Constant Mass Flow Rate

5.3.3.1 Extrusion Parameters

The torque and specific mechanical energy (SME) response to different proportions of pumpkin in the ingredients at different screw speeds are presented in **Figure 5-9** and **Figure 5-10**. Increasing the proportion of pumpkin flour in the formulations decreased torque and SME. However, the rate of reduction in torque and SME was not constant over the range of pumpkin flour added to the formulation. When pumpkin flour was added, the torque decreased to about 60% of the value for corn grits only and the SME decreased to about 45% of the value for the corn grits alone when pumpkin flour was added to the ingredients (**Figure 5-9** and **5-10**). At all proportions of pumpkin flour, torque and SME were constant, except for torque at 250 rpm (**Figure 5-9**) which was constant at 10% or more of added pumpkin flour. The result also indicated that increasing the screw speed from 250 to 350 rpm at all pumpkin flour proportions decreased the torque during processing but not the SME.

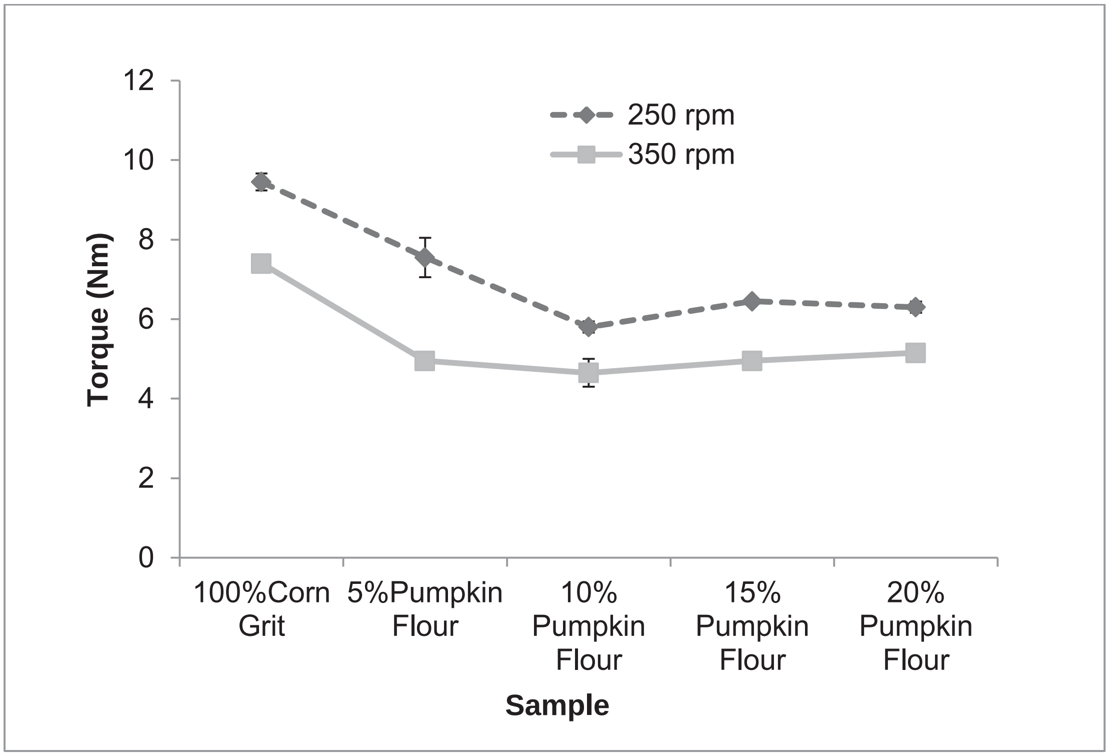


Figure 5-9: Effect of screw speed and the proportion of pumpkin flour on torque during extrusion. Error bars indicate standard deviations.

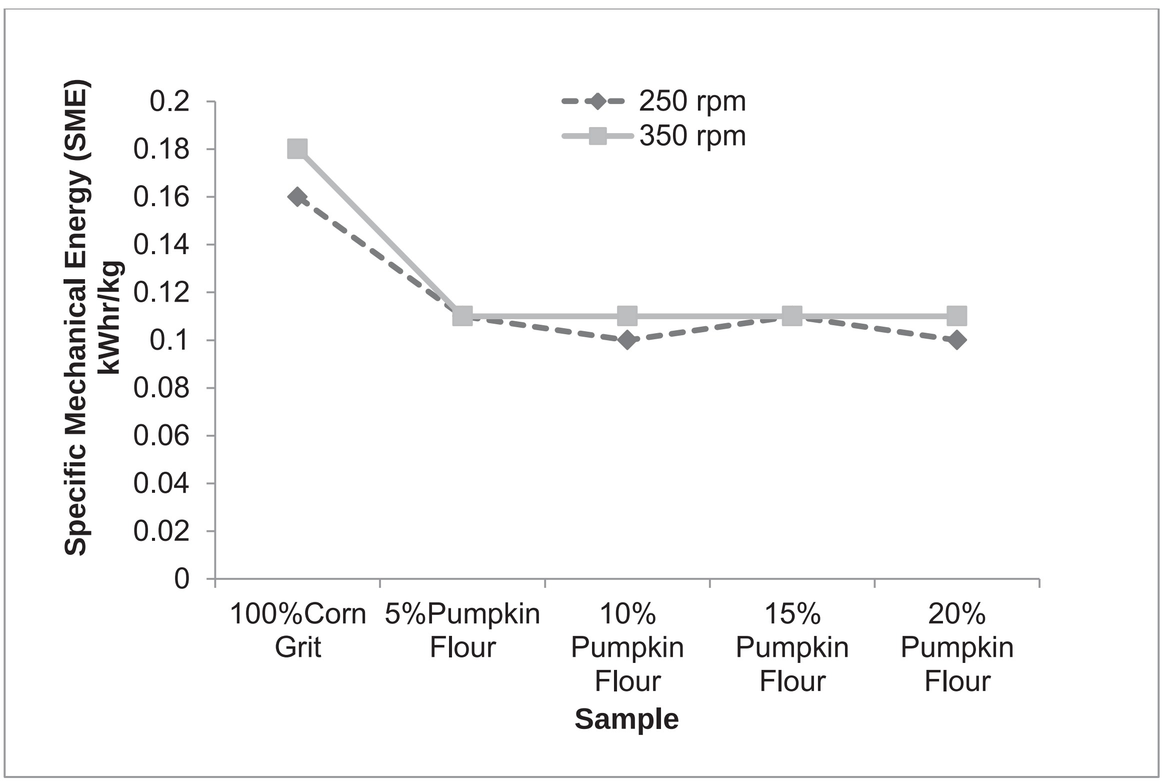


Figure 5-10 : Effect of screw speed and the proportion of pumpkin flour on the specific mechanical energy (SME). Each value was an average of duplicate samples.

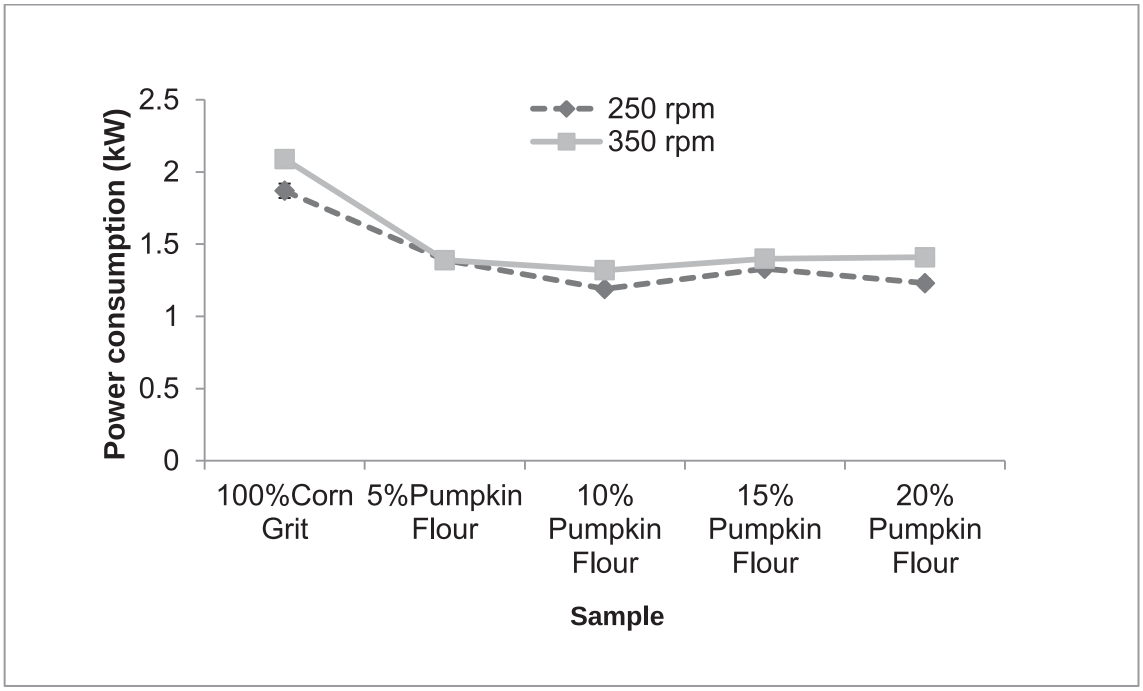


Figure 5-11 : Effect of screw speed and the proportion of pumpkin flour on power consumption (kw) during extrusion.

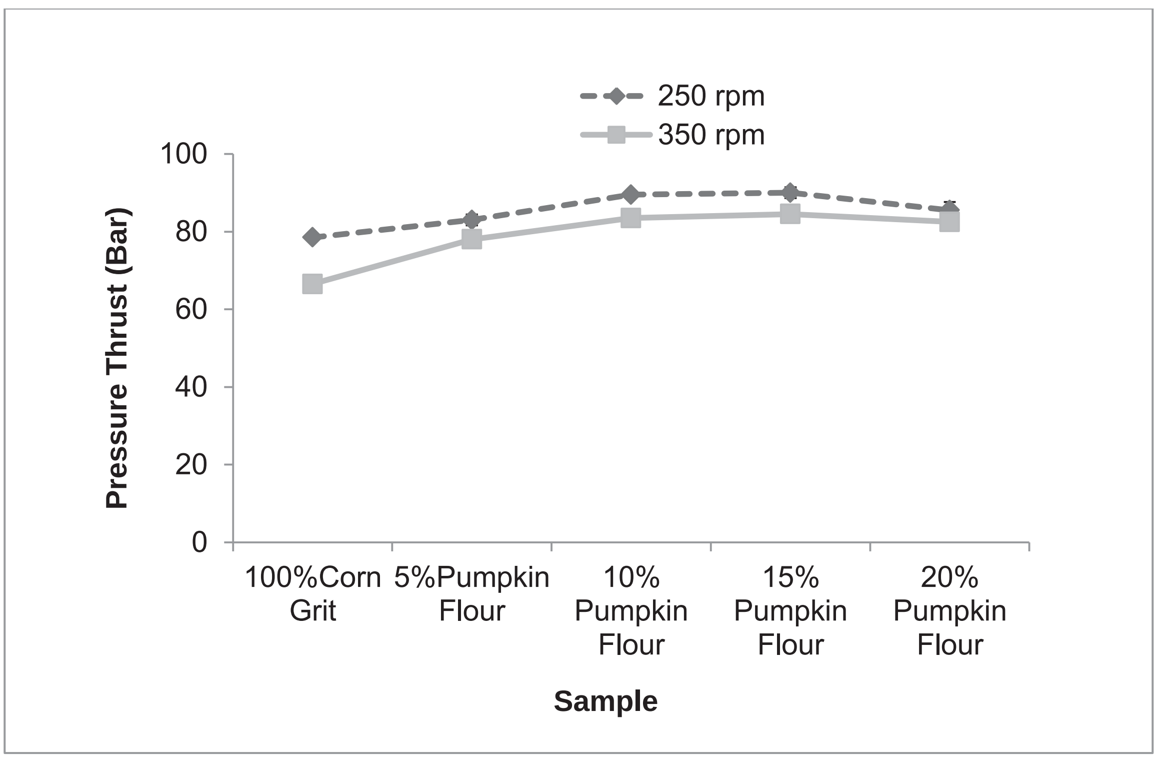


Figure 5-12 : Effect of screw speed and the proportion of pumpkin flour on pressure thrust during extrusion. Error bars indicate standard deviations.

5.3.3.2 Physical Characteristics of Extruded Products

Figure 5-13 and **Figure 5-14** below show extruded products made from different combinations of pumpkin flour and corn grits at screw speeds 250 rpm and 350 rpm respectively.

100% Corn grits | 5% Pumpkin Flour | 10% Pumpkin Flour | 15% Pumpkin Flour | 20%Pumpkin Flour

Figure 5-13 : Effect of screw speed (250rpm) and the proportion of pumpkin flour on the physical characteristics of extruded products.

100% Corn grits | 5% Pumpkin Flour | 10% Pumpkin Flour | 15% Pumpkin Flour | 20%Pumpkin Flour

Figure 5-14 : Effect of screw speed (350rpm) and the proportion of pumpkin flour on the physical characteristics of extruded products.

5.3.3.3 Expansion Ratio and Hardness of Expanded Snack Product

Increasing the proportion of pumpkin flour from 0 to 10% for the 350 rpm treatment decreased the expansion ratio of the extruded pellets by about 15%, but no further change occurred as the proportion of pumpkin flour was increased to 15 and 20%. At a screw speed of 250rpm the expansion ratio did not change significantly with the proportion of pumpkin flour in the ingredients as shown in Figure 5-15. As expected, the hardness of the extruded products varied inversely with respect to the expansion ratio and harder products tended to be less expanded although this was less evident for the product extruded at 250 rpm.

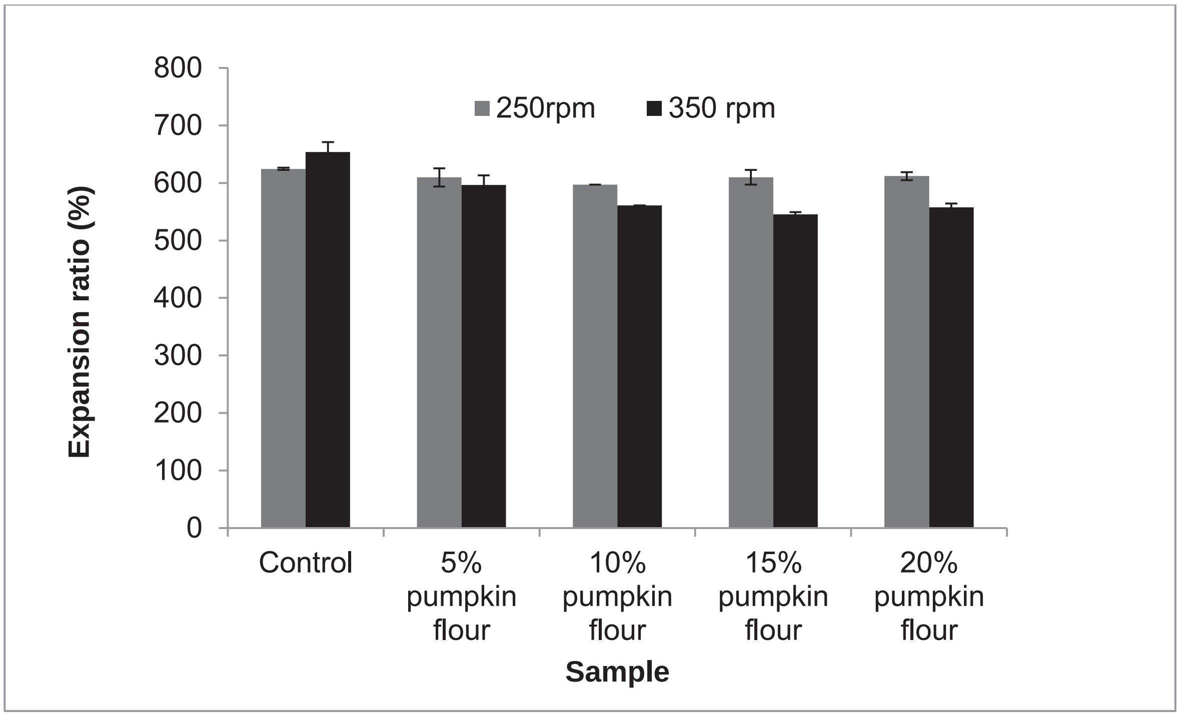


Figure 5-15 : Effect of screw speed and the proportion of pumpkin flour on the expansion ratio. Error bars represent the standard deviation.

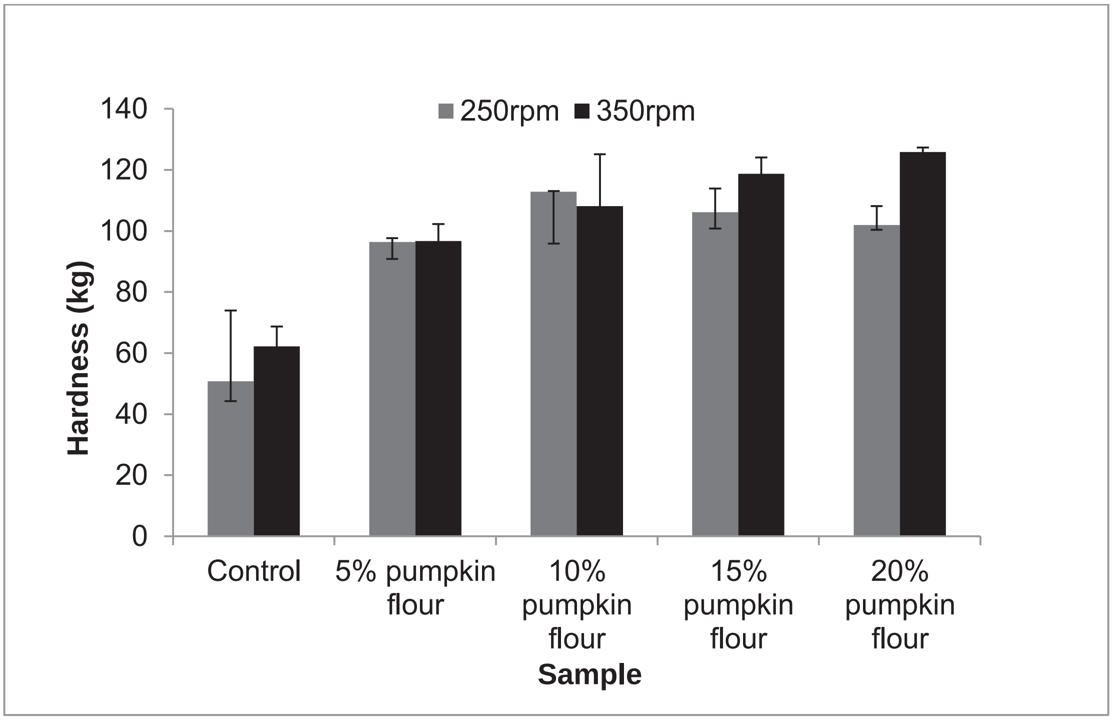


Figure 5-16 : Effect of varying pumpkin flour percentage and screw speed on the hardness of extrudates. Error bars indicate the standard deviation

5.3.3.4 Density of Expanded Snack Product

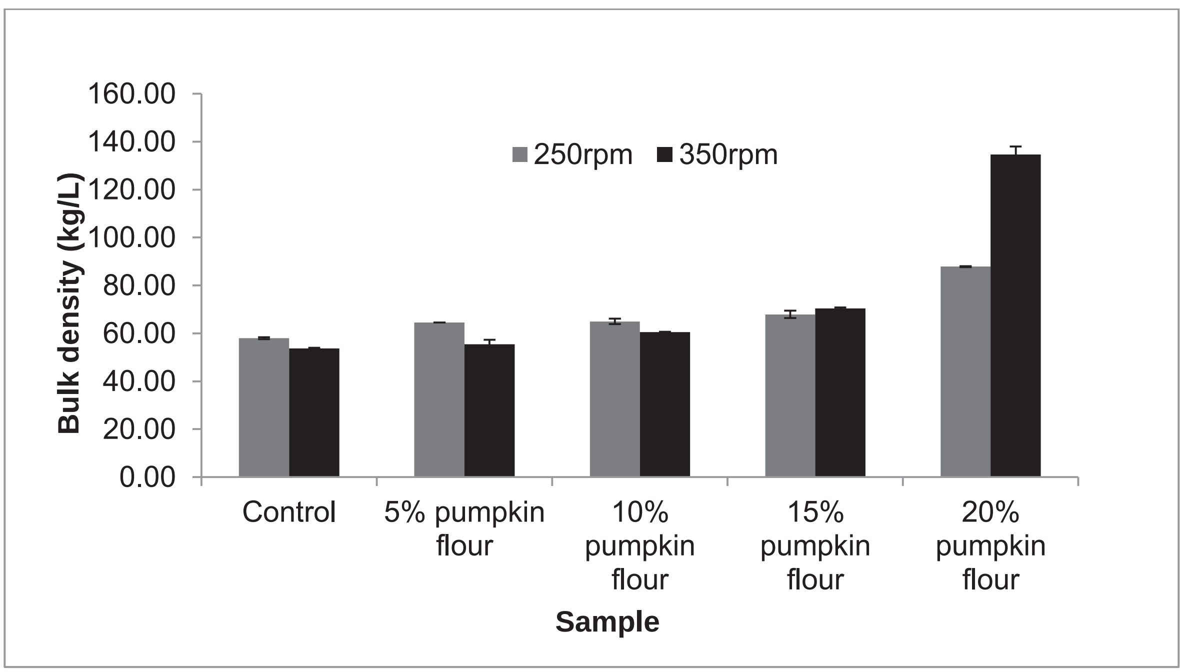


Figure 5-17 : Effect of varying pumpkin flour percentage and screw speed on the bulk density of extrudates. Error bars indicate the standard deviation

Bulk density (BD) and true density (TD) of the expanded pellets are shown in **Figure 5-17** and **Figure 5-18**. The bulk density ranged from 53.7 for the corn pellets to 134.7 kg/L for those containing 20% pumpkin flour. The true density was about 1.7 times greater than bulk density and ranged from 94.4 to 226.0 kg/L. As the level of pumpkin flour added into the blend was increased from 0 to 15% the BD and TD only increased by 5-15% for the 350 rpm screw speed. However when the level of pumpkin flour was increased from 15% to 20% the BD and TD approximately doubled. At a screw speed of 250 rpm, BD and TD increased by only 25% and 15% respectively as the pumpkin flour content was increased from 15 to 20%.

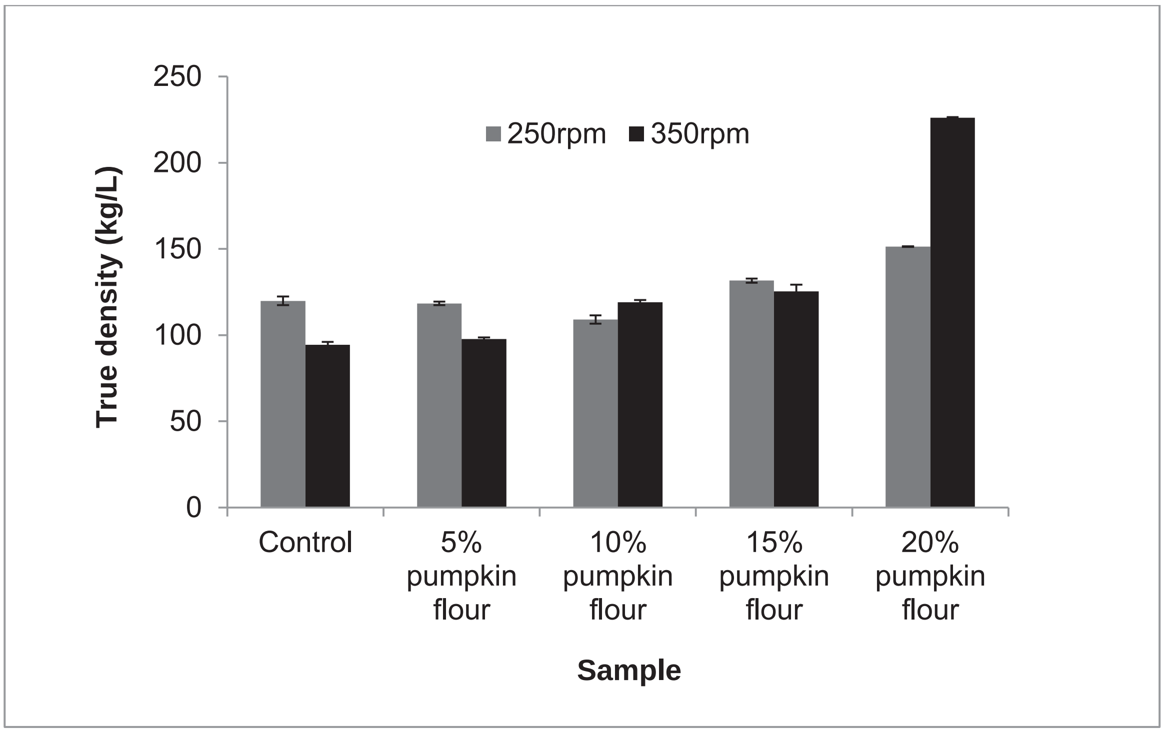


Figure 5-18 : Effect of varying pumpkin flour percentage and screw speed on the true density of extruded products. Error bars indicate the standard deviation

5.3.3.5 Pearson Correlation Interrelationship

Table 5-4 : The effect and relationships between experiment variables, control variables and physical characteristics of extruded snacks made from pumpkin flour-corn grits.

	Experimental Variable			Control Variable				Measured Variable			
	Screw Speed (rpm)	*Percentage of Corn Grits (%)*	*Percentage of Pumpkin Flour (%)*	*Power Consumption (kW)*	*Torque (Nm)*	*Pressure Thrust (Bar)*	*Specific Mechanical Energy (kWhr/kg)*	*Expansion Ratio (longitudinal)*	*Hardness (kg)*	*Bulk Density (kg/l)*	*True Density (kg/l)*
Screw Speed (rpm)	1.00										
Percentage of Corn Grits (%)	0.00	1.00									
Percentage of Pumpkin Flour (%)	0.00	-1.00	1.00								
Power Consumption (kW)	0.21	0.70	-0.70	1.00							
Torque (Nm)	-0.58	0.58	-0.58	0.63	1.00						
Pressure Thrust (Bar)	-0.49	-0.65	0.65	-0.86	-0.32	1.00					
Specific Mechanical Energy (kWhr/kg)	0.14	0.72	-0.72	0.99	0.67	-0.83	1.00				
Expansion Ratio (longitudinal)	-0.43	0.58	-0.58	0.58	0.74	-0.49	0.63	1.00			
Hardness (kg)	0.18	-0.78	0.78	-0.79	-0.81	0.64	-0.84	-0.76	1.00		
Bulk Density (kg/l)	0.14	-0.74	0.74	-0.29	-0.30	0.25	-0.35	-0.44	0.53	1.00	
True Density (kg/l)	0.09	-0.73	0.73	-0.26	-0.23	0.28	-0.31	-0.45	0.48	0.98	1.00

Table 5-4 above shows the correlation coefficients for the relationship between experimental variables, the control variables and physical characteristics of extruded products made from pumpkin flour and corn grits.

26% of the variables were found to be correlated with a value for r^2 that was greater than 0.5. Screw speed was found to be negatively correlated (r^2=-0.58) with torque. This indicates that, as screw speed increased, torque decreased due to lower barrel fill which may decrease the resistance against melt viscosity and thus result in lesser resistance to screw rotation and lower motor torque (Lu., 1992).

Another possible explanation is that the increased shear rate resulting from the increases in screw speed results in an increased level of shear thinning of the melt. It is also expected that the melt temperature will increase with shear also contributing to decreases in melt viscosity.

When pumpkin flour was added to the formulations power consumption (r^2=-0.70), torque (r^2=-0.58) and SME (r^2=-0.72) decreased. This shows that the three parameters were proportional to the product expansion. The presence of sugar, fibre and pectin in pumpkin flour reduce melt viscosity so reducing power decreased the expansion of the final product. SME was found to be highly positively correlated to power consumption (r^2=0.99). As expected, hardness was found to be correlated to bulk density (r^2=0.53) and true density (r^2=0.48).

5.3.4 Texture Analysis of Product Mapping

A random and general texture mapping of commercial snack foods was used to compare the hardness and crispiness of pumpkin flour – corn grits expanded snack products. It was also used as a standard reference in order to get a desired texture acceptable to the consumers. However, this cannot be a true comparison due to different raw ingredients used, different extrusion conditions used and moreover, most of the commercial snacks were coated with seasoning that may lower the hardness and crispiness. Therefore due to this phenomenon, pumpkin flour-corn grits expanded snacks were found to be harder with less crispiness. This is shown in **Figure 5-19**. Hardness of some of the samples fell within the range of commercial snacks. Two different patterns are observed in the graph. Therefore, it will be a great challenge to develop the desired and accepted texture with pumpkin flour – corn grits. Recommendation: use a different grain based flour such as rice flour or other grains.

Hardness of this expanded snack was found to be acceptable but crispiness may need to be improved.

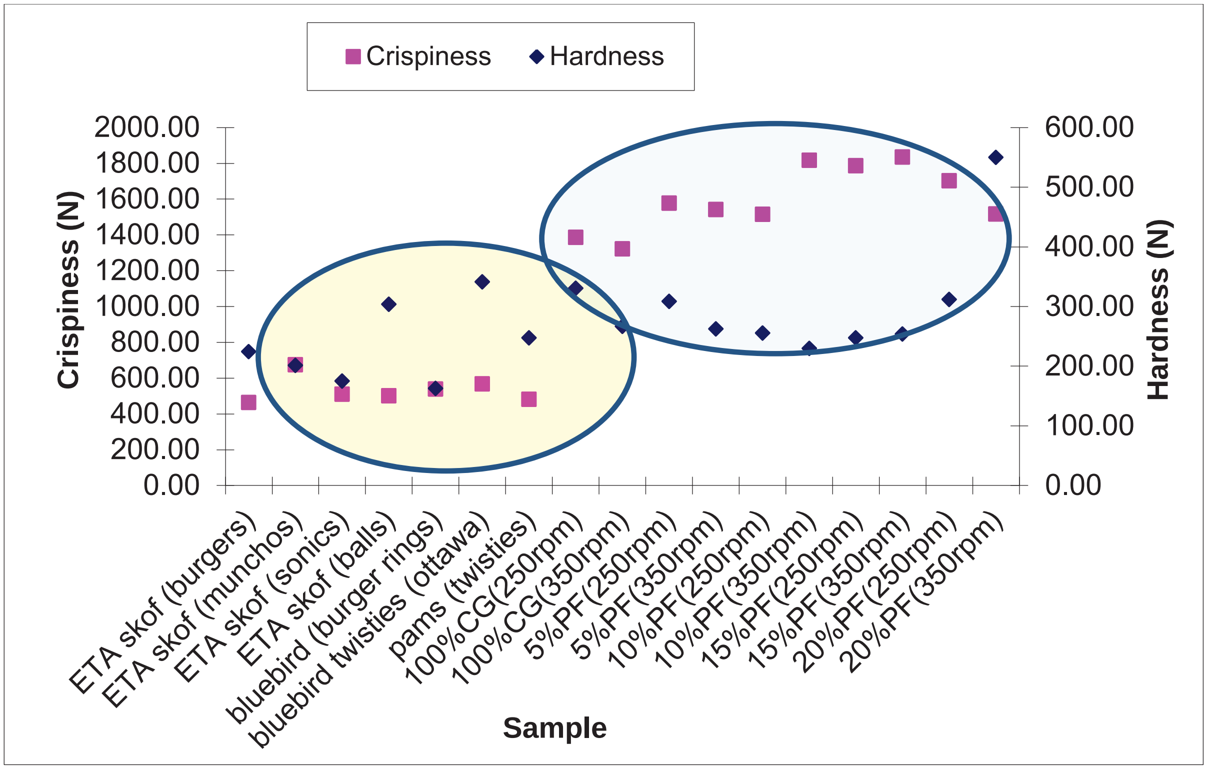


Figure 5-19: Texture mapping of pumpkin flour – corn grits snack with commercial snack products

5.4 Conclusion

As the proportion of pumpkin flour increased, torque and SME decreased showing that the viscosity of the melt formed within the extruder during processing decreased. This was probably due to the high proportion of pectin (14-22%) and sugar (37%) in the pumpkin flour that reduced the viscosity of the melt compared with a melt formed from corn grits only. This effect has been previously shown for ingredient mixes that contain high levels of sugars (Jin, Hsieh & Huff ,1995)). Melts containing higher sugar levels also decrease the viscosity of the melt as it leaves the die thus delaying setup of the expanding melt. As a consequence, the bubbles of steam cool and the melt collapses to some degree causing shrinkage and decreased expansion of the extruded product (Carvalho & Mitchell, 2000).

During this work it was possible to keep the SME near constant for all treatments except the 100% corn grits for which torque and SME were about 64% greater than for the treatments including pumpkin flour. The lubricating effect of the sugar and pectin components in the pumpkin flour were clear although it is surprising that the effect stabilised after the addition of 5% of pumpkin flour. This effect is evident throughout this work and the expansion ratio, hardness, densities and probably the void area of extruded product made with 10, 15 or 20% of pumpkin flour were not significantly different. This may be because the sugar and pectin in the pumpkin flour preferentially coats the working surfaces in the extruder possibly by the formation of a depletion layer.

As the proportion of pumpkin flour increased from 0 to about 10%, the extruded pellets approximately doubled in hardness but decreased in their true density. Among the variables, power consumption and SME were found to have a higher value of positive correlation (r^2=0.99).This work has shown that snack foods can be produced from combinations of corn grits and pumpkin products. Although, the texture of this product was about 40% harder than for typical corn based products the bulk density was similar up to the addition of 15% of pumpkin flour. Preliminary work (Hardacre unpublished) had shown that at levels of pumpkin flour of greater than 20% very little expansion in the extruded products could be achieved. At all levels of added pumpkin powder below 20%, the hardness of the pellets seemed to be determined by the strength of the bubble walls and not by the number and distribution of bubbles measured as the void volume in the extruded pellets or by bulk density (as discussed in section 7.3.4.)

Chapter 6: Product Optimisation

In this chapter, Response Surface Methodology (RSM) and its application in steady state modelling of the extrusion processing of pumpkin flour –corn grits snacks are discussed with a particular focus on process conditions, extrusion parameters and product characteristics.

6.1 Introduction

Response surface methodology (RSM) refers to a group of statistical and mathematical techniques for developing, improving and optimising processes (Bas& Boyaci., 2007).Giovanni (1983) defines Response Surface Methodology (RSM) as a statistical mathematical method that uses quantitative data in an experimental design to determine and simultaneously solve multivariate equations, in order to optimise processes and products. Myers and Montgomery (2002) stated that, the application and results of RSM cover the effects of the independent variables and their combination on the process. Originally the principles and ideas of RSM were presented by Box and Wilson (1951).The application of RSM has since covered a wide range of design and development, enabling the optimisation of new product formulation and improvement of existing products in various industries such as polymers and the food industry. RSM is a good tool for providing information from a large amount of data within the shortest time and with the least amount of analysis and can also be used to determine interactions and relationships among variables. Moreover, RSM is a useful tool to optimise a process. However, the disadvantage of RSM is that the data transformation process for a non-linear system may not give desirable results and thus may need more critical determination of the independent parameter range for more precise analysis.

Regression equations are the primary results obtained, and these are used to interpret the importance and significance for each variable, to determine the interactions and relationships between variables and also to predict the pattern of relationships such as a linear, curved or quadratic response surface (Olkku, Hagqvist & Linko, 1983). A good indicator and prediction of the model can be determined by a non-significant lack of fit (Myers & Montogomery, 2002). The coefficient of variation (C.V) is used to measure the reproducibility of the models, where if the CV is not greater than 10% ,it can be considered as a reasonable and reproducible model (Firatligil-Durmus & Evranuz, 2010). The C.V also indicates the relative dispersion of the experimental points from the prediction models. The coefficient of determination (R^2) is the ratio of the explained variation to the total variation and is used to measure the degree of fit (Haber & Runyon., 1977). Overall the adequacy of the models is based on model analysis, lack-of-fit test and the coefficient of determination (R^2) (Lee, Ye, Landen & Eitenmiller (2000); Weng, Liu & Lin (2001)). If the adequate precision value is greater than 4.0, the model can be used to navigate the design space (Montgomery & Wiley, 2001).

Extrusion processes are affected by numerous parameters and basically can be divided into three main variables; Process variables, Extrusion variables and Product characteristics variables. Prediction and optimisation of product quality in the food industry is a major concern (Olkku, Hagqvist & Linko, 1983) especially in developing new snack products from new to extrusion raw material such as pumpkin flour where it is unknown how such an ingredient behaves. Therefore, the objective of this experiment was to determine by using RSM the optimum combination of extrusion variables for the production of an extruded product from pumpkin flour when used in combination with corn grits which is a more common snack extrusion ingredient.

6.2 Materials and Methods

6.2.1 Extrusion Conditions

Extrusion was performed using a Clextral B21 twin-screw co-rotating laboratory scale extruder (Clextral, Firminy Cedex, France) with three different screw configurations; A-Forward, 13mm pitch, 50mm length, B-Forward, 10mm pitch, 50mm length, C-Forward, 7mm pitch, 50mm length. The extruding was running at a constant screw speed of 300rpm with 55rpm cutter speed. A die opening of 3.0 mm diameter was used. The internal barrel width was 46mm, height 25mm and screw diameter 24.7mm.

6.2.2 Experimental Design

Response Surface Methodology (RSM) was used to find ideal and optimal process parameters for the pumpkin-corn grits extrusion. The experimental design was based on a central composite design (CCD) with three independent variables X_1- barrel temperature, X_2- feed rate, and X_3- percentage of pumpkin flour. Dependent variables were the extrusion parameters of torque, SME, power consumption, and pressure thrust and the physical characteristics of expansion, bulk density, true density, hardness, colour analysis and total carotenoid. The plot generations and statistical analysis were performed using the commercial statistical package of Design Expert software version 6.0.2 (Statease Inc., Minneapolis, MN, USA). The three levels of process variables were coded as -1, 0 and 1 as shown in Table 6-1 below. The actual levels of extrusion conditions are summarised in **Table 6-3.**

Table 6-1 : Coded levels for the independent variables

Variable	α		Coded level		α
	-1.682	-1	0	1	1.682
X_1 – Barrel Temperature (C)	116.36	130	150	170	183.64
X_2 – Feed Rate (kg/hr)	9.99	10.5	11.25	12	12.51
X_3 – Pumpkin Flour (%)	0	5	15	25	31.82

The alpha (α) represents low and high values for each factor; Barrel temperature, Feed rate and pumpkin flour percentage respectively. The value of α depends on the number of factors in the factorial part of the design as shown in **Table 6.2** below.

Table 6-2 : Determining α for Rotatability

Number of Factors	Factorial Portion	Scaled Value for α Relative to ±1
2	2^2	$2^{2/4} = 1.414$
3	2^3	$2^{3/4} = 1.682$
4	2^4	$2^{4/4} = 2.000$
5	2^{5-1}	$2^{4/4} = 2.000$
5	2^5	$2^{5/4} = 2.378$
6	2^{6-1}	$2^{5/4} = 2.378$
6	2^6	$2^{6/4} = 2.828$

Table 6-3 : Extrusion conditions with actual variable levels for experimental design

Run	Barrel temperature (C)	Feed rate (kg/hr)	Pumpkin level (%)
1	150.00	12.51	15.00
2	150.00	11.25	15.00
3	150.00	9.99	15.00
4	183.64	11.25	15.00
5	130.00	10.50	25.00
6	170.00	12.00	25.00
7	116.36	11.25	15.00
8	130.00	12.00	5.00
9	150.00	11.25	15.00
10	150.00	11.25	31.82
11	150.00	11.25	0
12	150.00	11.25	15.00
13	150.00	11.25	15.00
14	170.00	10.50	25.00
15	170.00	10.50	5.00
16	150.00	11.25	15.00
17	130.00	12.00	25.00
18	150.00	11.25	15.00
19	170.00	12.00	5.00
20	130.00	10.50	5.00

6.2.3 Extrusion Parameters Analysis

Extrusion parameters consisting of power consumption, torque, specific mechanical energy (SME), and pressure thrust were analysed according the methods mentioned in **Chapter 5.**

6.2.4 Product Analysis

Expansion, density, hardness and colour analysis on extruded product were determined as described in **Chapter 5**.

6.2.5 Total Carotenoid Analysis

Extraction of carotenoid in the pumpkin flour – corn grits extruded product was carried out according to the method of Kean, Hamaker and Fernizi., (2008) with minor modifications. A 1 gram sample was homogenised/dissolved in/with 5 ml of a 10mg/ml porcine pancreatin solution and then incubated at 37°C in a shaking water bath for 20 minutes. A 20 ml aliquot of a solvent mixture comprised of petroleum ether: acetone (3:1 v/v) containing 0.1% (w/v) butylated hydroxytolouene (BHT) was added and shaken vigorously for 1 min to facilitate the separation. The suspension was held at room temperature and minimum light exposure for 15 minutes to allow further separation of polar (water) and nonpolar (solvent) phases. The upper layer containing total carotenoid was collected and the absorbance at 450nm was measured using a UV-visible spectrophotometer (Helios Epsilon spectrophotometer; Thermo Electron Corporation, Pittsford, NY, USA). For data quantification, a standard curve of pure carotene solution was prepared.

6.2.5.1 Total Carotenoid Standard Curve

A series of concentrations ((0.01, 0.02, 0.03, 0.04, 0.001 and 0.02 mg/ml) of β-carotene standard purchased from Sigma-Aldrich,NZ Ltd were dissolved in petroleum ether. The colour intensity of the β-carotene was then measured at ʌ=450nm and a standard calibration curve of concentration versus absorbance was plotted with R^2= 0.9904.

6.3 Results and Discussion

6.3.1 Extrusion Parameters

Extrusion parameters play a major role in extrusion processing and they reflect the energy consumption and extruder efficiency during the process. Moreover they also influence the final product characteristics. The effect of process conditions of X_1 – barrel temperature, X_2- feed rate and X_3- pumpkin flour percentage on the power consumption, torque, thrust pressure and specific mechanical energy (SME) were studied.

The regression models for power consumption(kw), torque (Nm), pressure thrust (Bar) and specific mechanical energy (SME) showed r^2 >0.5. None of the models show significant lack-of-fit (P>0.05).

Effect of barrel temperature, feed rate and pumpkin flour percentage on power consumption is shown in Figure 6-1 below. Power consumption was taken from motor power reading during the extrusion process

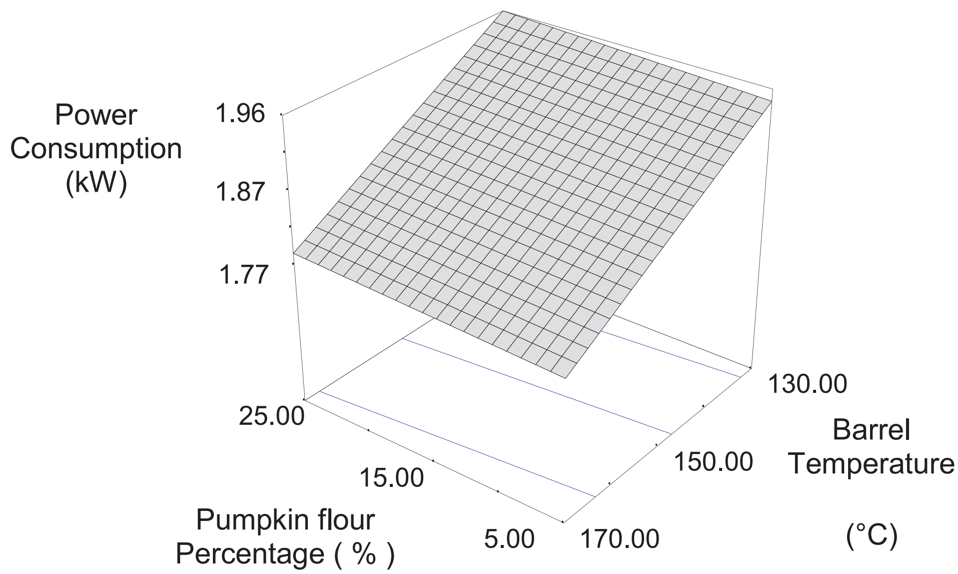


Figure 6-1 : Predicted response surface plot for power consumption (kW) as a function of pumpkin flour level (%) and barrel temperature (°C) at a feed rate of 11.25 kg/hr.

$$\text{Power consumption} = 1.87 - 0.088X_1 + 0.12X_2 + (7.622 \times 10^{-3})\, X_3 \text{ ------------------ } (1)$$

Equation (1) above shows the regression equation of power consumption for the extrusion processing of pumpkin flour – corn grits snacks. Power consumption is proportional to increases in the level of pumpkin flour and feed rate, this is shown by a positive correlation in the equation (1). Therefore, added pumpkin flour with higher feed rate may increase the power consumption during the extrusion process. A negative correlation was found between power consumption and barrel temperature.

Torque in extrusion is used as a safety indicator as torque fluctuation indicates non-steady state extrusion conditions. The torque value also provides information on the energy absorbed by material due to shear exerted by screws (Fitchtali & Van de Voort, 1989). The torque value must be kept constant during the extrusion process in order to provide stable processing conditions. The results of this work showed that torque ranged from 5.85 – 9.30 Nm.

Figure 6-2 shows response surface plot for torque (Nm) as a function of pumpkin flour level (%) and barrel temperature (°C) at a feed rate of 11.25 kg/hr.

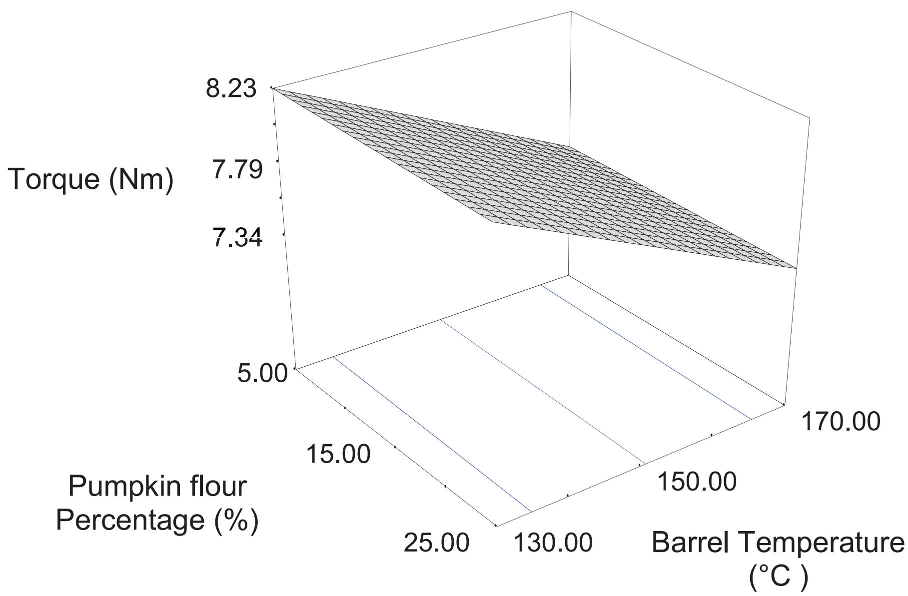


Figure 6-2 : Predicted response surface plot for torque (Nm) as a function of pumpkin flour level (%) and barrel temperature (°C) at a constant feed rate of 11.25 kg/hr.

The predicted model for torque in this experiment is as follows:

$$\text{Torque} = 7.79 - 0.44X_1 + 0.56X_2 - (6.957 \times 10^{-3})X_3 \quad \text{-----------------------}(2)$$

Based on the equation (2) above, torque was found to be negatively correlated with the barrel temperature (X_1), thus indicated increased of barrel temperature, decreased torque value at pumpkin flour at 15%. The coefficient of variation (C.V) of the torque was found to be relatively less than 10% (C.V= 7.17), which indicates that this model can be used in optimising the extrusion conditions for a pumpkin flour-corn grits extrudate snack. A positive correlation is shown between the torque and feed rate. As feed rate increased, there was a concomitant increase in torque. Increasing the feed rate may result in development of the resistance required to turn the screw as the number of filled flight of extruder barrel increased. Therefore, there is a need for more mechanical power to dissipate into the material during extrusion processing, as a result the value of torque will increase (Liang, Huff & Hsieh, 2002).

The effects of pumpkin flour percentage, barrel temperature and feed rate on specific mechanical energy (SME) of extruded snacks made from a pumpkin flour- corn grits mixture are shown in **Figure 6--3.**

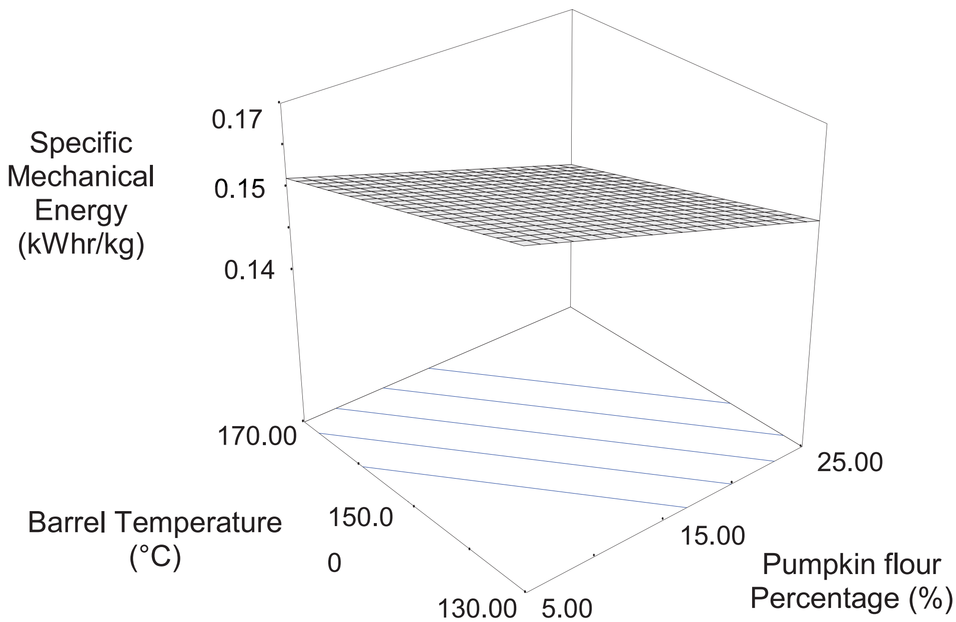


Figure 6-3 : Response surface plot for specific mechanical energy (kwhr/kg)as a function of pumpkin flour level (%) and barrel temperature (°C) at a feed rate of 11.25 kg/hr.

Specific mechanical energy

(SME) = 0.16 – (6.024×10^{-3}) X_1 + (1.714×10^{-3}) X_2– (7.722×10^{-3})X_3 --------------------(3)

The regression equation for SME was fitted using a linear model as stated above (equation 3). No interaction among the variables was found. The analysis of variance (ANOVA) for SME indicates a linear effect with r^2 = 0.5357 at P<0.01 and coefficient of variation (C.V) 5.41. As the correlation coefficient value (r^2) <0.6 the relationship is not strong, but the C.V was <10% which indicates that this model is reliable and can be applied to the extrusion processing of pumpkin flour-corn grits mixtures. The F-value for SME was found to be significant (P<0.05), while the lack of fit was not significant (P>0.05). As the SME increases, the barrel temperature decreases, which is a similar result to that reported by Altan, McCarthy and Maskan, (2008) for a barley-pomace extrudate product. The effects of pumpkin flour level and barrel temperature on SME are shown in Figure 6-3 above. It is evident from Figure 6-6 that the higher the SME value the better the product's expansion. From equation (3) there are three ways of increasing SME, however for a given pumpkin – corn grits formulation this reduces to two variables. Although decreasing X1 (barrel temperature) will increase SME it will result in reduced expansion as the driving force for expansion is related to the rate of liquid water converting to vapour on the release of pressure upon exiting the die. The rate of conversion from liquid water to vapour is relative to the magnitude of the temperature difference between the liquid water in the extrudate at the point of die exit and the boiling point of water under the pressure conditions of the post-die environment. Therefore the only lever available to the manufacturer to increase SME is through increasing the feed rate (X2). In contrast a lower SME resulted in reduced expansion. According to Erdemir (1989) a lower SME results in a lower degree of molecular breakdown of starch and thus will reduce the expansion.

$$\text{Pressure thrust} = 69.22 - 11.30X_1 + 3.14X_2 + 2.53X_3 \quad \text{--------------------------} \quad (4)$$

The RSM analysis suggested that a linear relationship exists between the pressure thrust and the three process variables assessed in this work. The main variable affecting pressure thrust was the barrel temperature which had approximately 4-5 times the effect on pressures thrust as feed rate (X2) and the level of pumpkin flour (X1). At low barrel temperature, pressure thrust increased only incrementally with increases in either feed rate or pumpkin flour level. Analysis of variance, shows that the model as a whole has a high correlation coefficient (r^2= 0.8561) with the model accounting for 85% of the total variation observed in the data collected. The model is also reliable with a C.V. of less than 10% (C.V= 6.57). The regression was found to be statistically significantly with a P value of <0.001). No interaction between variables was found. The response surface plot for pressure thrust is shown in **Figure 6-4.**

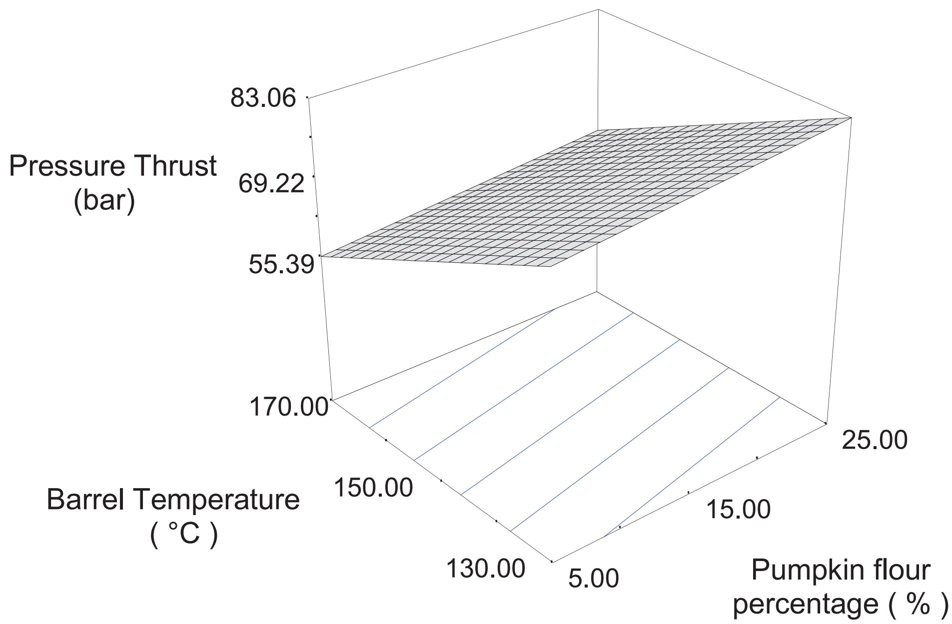


Figure 6-4 : Response surface plot for pressure thrust as a function of pumpkin flour level (%) and barrel temperature (°C) at a feed rate of 11.25 kg/hr.

Power consumption, torque, specific mechanical energy and pressure thrust were found to be closely related and need to be monitored during extrusion processing in order to get stable conditions, and therefore control the product quality characteristics. Specifically SME and torque should be kept constant to ensure product reproducibility and quality.

6.3.2 Product Characteristics

Expansion is generally defined as the ratio of the extrudate diameter, or cross-sectional area relative to that of the die. Alvarez-Martinez, Kondury and Harper (1988), divided the expansion into five (5) categories; sectional, longitudinal, volumetric, the specific length of extrudate based on a constant unit of mass and the specific volume of extrudate per unit mass. However, in this study only sectional and longitudinal expansion was assessed. **Figure 6-5** shows the product expansion characteristics.

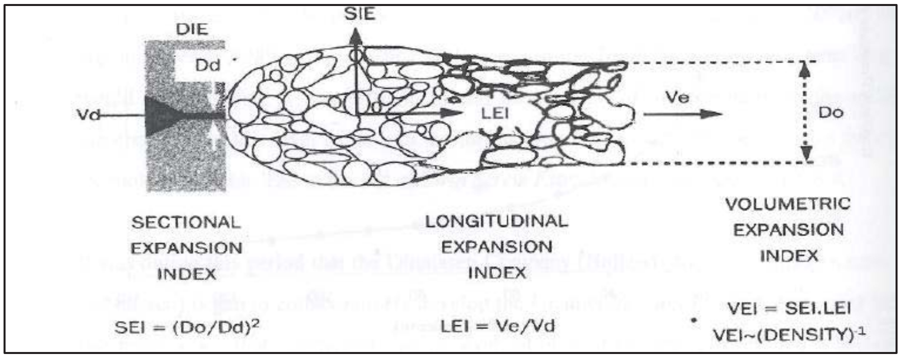


Figure 6-5 : Product expansion characteristics

$$\text{Longitudinal Expansion} = 22.28 + 1.59X_1 + 0.93X_2 - 0.64X_3 \quad \text{---------------------------- (5)}$$

The Longitudinal Expansion Index is calculated using the ratio of the exiting velocity of the extrudate after expansion to its velocity in the die orifice. The response surface plot below (**Figure 6-6**) shows that longitudinal expansion increases with increases in barrel temperature and feed rate, however the expansion decreases with increases in barrel temperature above 183.64°C and above feed rates of 12.51kg/hr. This effect is thought to be due to excessive structure breakdown and starch degradation at high temperature and feed rate, which may result in structure collapse. A similar result has also been reported by Dogan and Karwe (2003) and Ilo, Tomschik, Berghofer and Mundigler., (1996). Increasing the level of pumpkin flour was found to be negatively correlated to the longitudinal expansion.

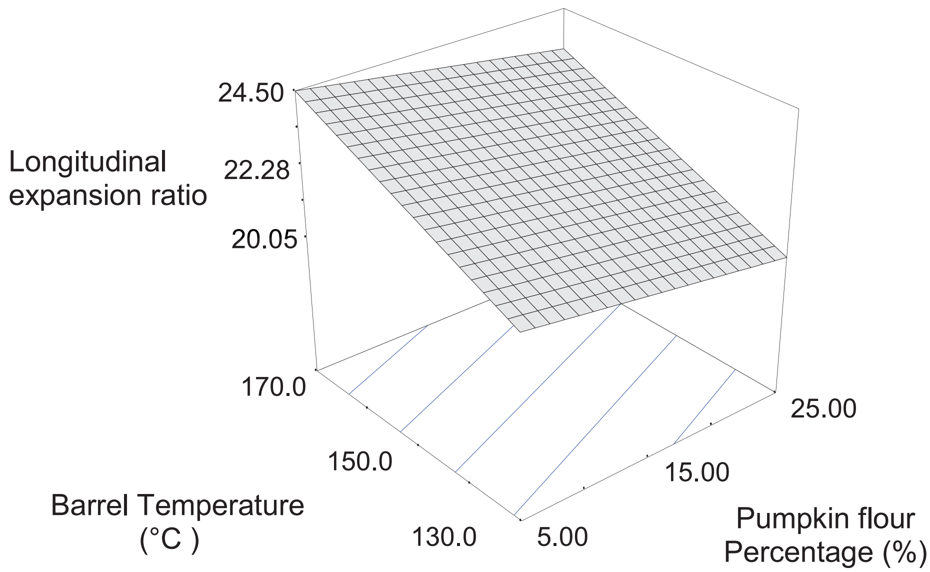


Figure 6-6 : Longitudinal expansion of extrudate product as a function of barrel temperature and pumpkin flour percentage at a constant feed rate of 11.25kg/hr

The maximum expansion ratio (24.73) of extrudate products at coded point (0,-1, 0) was about 1.4 times more than the minimum expansion (17.35) at the same coded point. The model of F-value of 10.35 implies that the model is of statistical significance with a P value of 0.05. This model can be used for prediction purposes as the adequate precision (10.931) is greater than 4.0 (Montgomery, 2001). The effect of barrel temperature, feed rate and pumpkin flour level on longitudinal expansion of the extrudate is shown in **Figure 6-6.**

Sectional expansion or radial expansion is referred to as the movement of cooked melt perpendicular to the flow.

Sectional expansion

$= 12.22 - 0.26X_1 + 0.36X2 - 2.14X3- 0.11X_1^2 + 0.12X_2^2 - 0.86X_3^2 + 0.27X_1X_2 + 0.47X_1X_3 - 0.056X_2X_3$ ---------------------------------- (6)

The response surface plot for sectional expansion of the extruded product as a function of barrel temperature and pumpkin flour concentration at a constant feed rate of 11.25kg/hr is shown in **Figure 6-7** below.

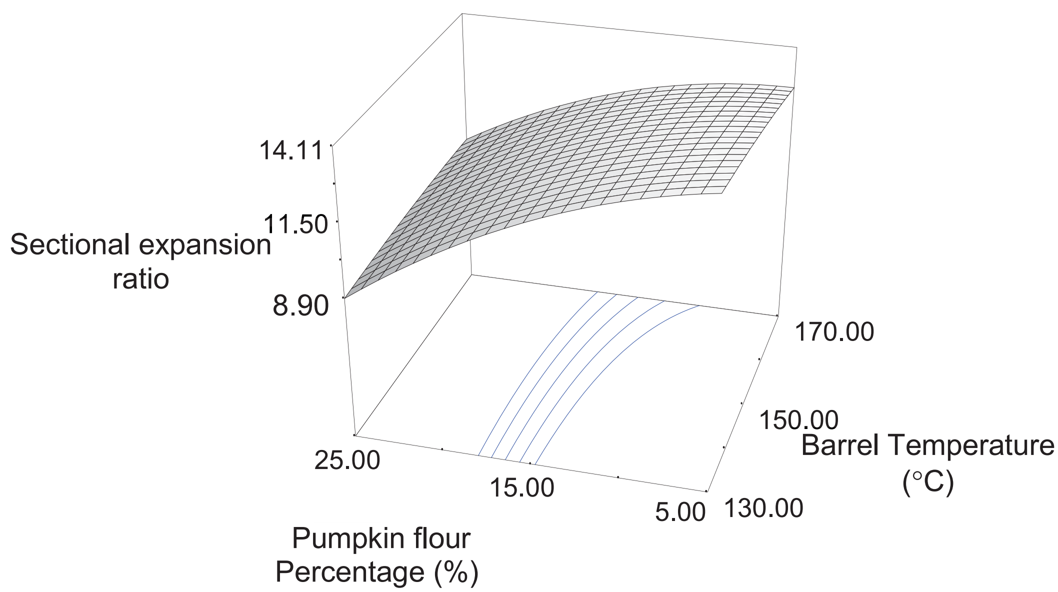


Figure 6-7 : Sectional expansion of extruded product as a function of barrel temperature and pumpkin flour concentration (%) at a constant feed rate of 11.25kg/hr

The model fitted to the sectional expansion ratio data is shown in equation 6 and unlike the other models presented earlier in this chapter include the quadratic as well as linear effects for all variables. The sectional expansion ratio of pumpkin flour –corn grits extruded products ranged between 8.2–14.59. A high value of coefficient of determination (r^2- 0.9090) with coefficient of variation (C.V = 7.63) less than 10% was observed.

Both of the analyses resulting from equations 5 and 6 indicate that the key variable affecting the longitudinal and sectional expansion ratios of pumpkin flour –corn grits extrudate products, is the barrel temperature which if increased leads to lower melt viscosity and hence would increase the longitudinal expansion and concomitantly decrease sectional expansion due to low elasticity. A key difference between the factors affecting both expansion ratios is that increasing the pumpkin flour level was found to result in only a decrease sectional expansion ratio. This result is attributed to the present of sugar, pectin and low starch content in the pumpkin flour. Jin, Hsieh and Huff., (1994) in their study of corn meal extrudate, reported that increases in the fibre content of the formulation would decrease the product expansion by rupturing the cell walls before the gas bubbles could expand to their full potential.

Extruded product colour is an important physical property that may attract or repel consumers to consume or buy such products. Therefore, colour is closely related to the acceptability of the product. The following analysis will benefit formulators and manufacturers to optimise some of these consumer acceptance qualities. The response plots for the lightness (L), redness (a) and yellowness (b) variables of pumpkin flour-corn grits extrudate snacks product as a function of coded independent variables are shown in **Figure 6-8, Figure 6-9** and **Figure 6-10** respectively.

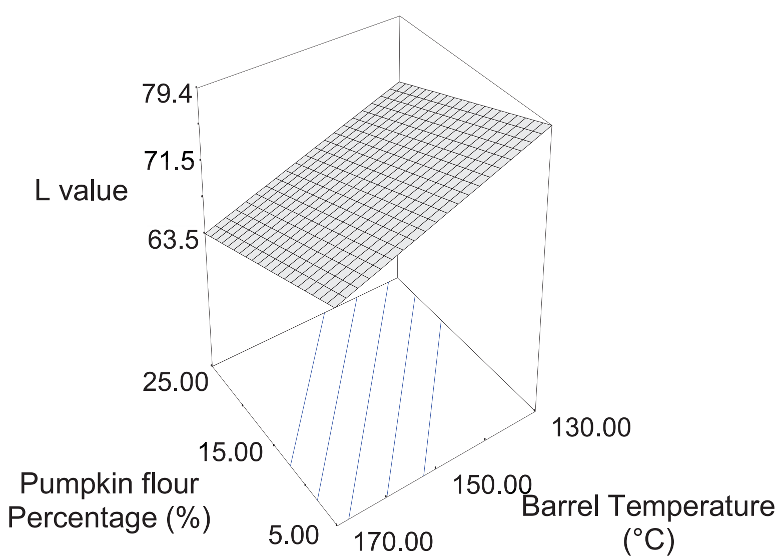


Figure 6-8 : Effect of barrel temperature, feed rate and pumpkin flour percentage on lightness (L value)

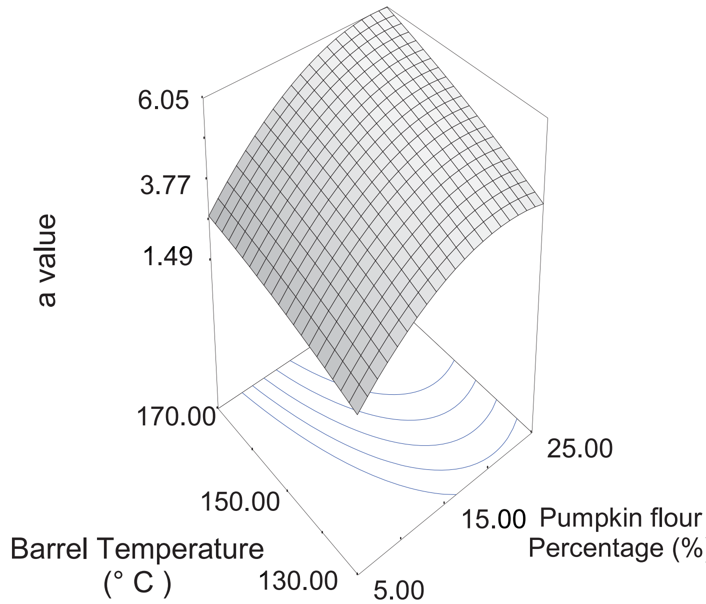


Figure 6-9 : Effect of barrel temperature, feed rate and pumpkin flour percentage on redness (a value)

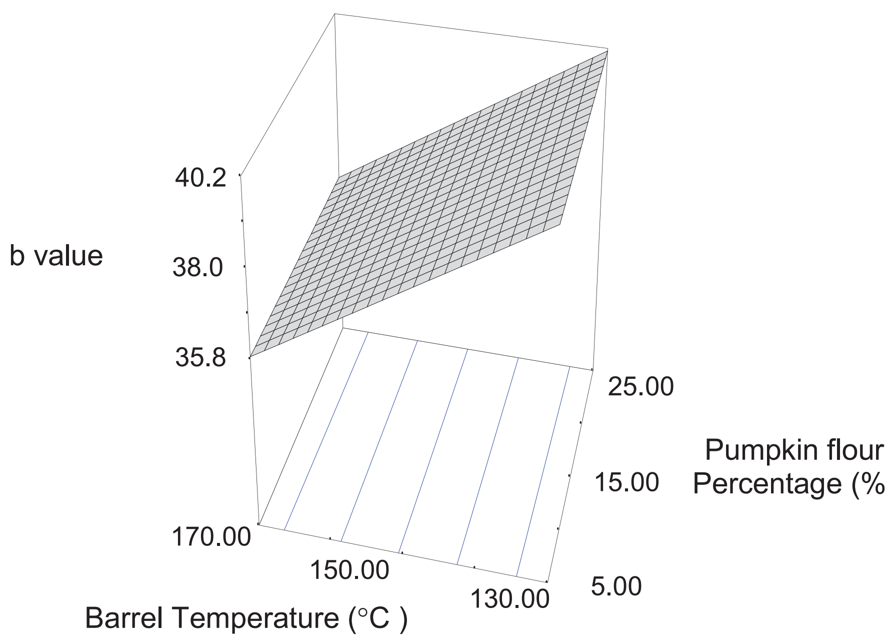


Figure 6-10 : Effect of barrel temperature, feed rate and pumpkin flour percentage on yellowness b value)

Linear effects were observed for L value and b value, and a quadratic effect was found to describe the relationship with redness (a value). A regression equation showing the relationship between the process variables and each of the parameters defining colour (i.e. the L, a and b values) are shown in **Table 6-4**. The highest *L value* was found at 150°C with 0% of pumpkin flour added while the lowest values of *L* and *a* were at 183.64°C, with 15% pumpkin flour added. The decreases in L values indicate that, the product become darker as when the barrel temperature increases and when pumpkin flour composition increases. This response is expected as chemically the system will be more prone to Maillard browning reactions at higher temperatures due to increased barrel temperatures, and at higher sugar levels, which would result from increases in the ratio of pumpkin flour to corn grits in the formulation. As reported in the literature pumpkin flour has a higher sugar concentration than corn grits. Additionally under high temperature processing conditions the rate of carotenoid pigment degradation in pumpkin flour would be expected to increase. These results are consistent with previous studies done by Maga and Kim (1989) and Altan, McCarthy and Maskan, (2008).The correlation coefficient (R^2) for the relationship between process parameters and L, a and b described in **Table 6-4** are 0.5060, 0.9540 and 0.7153 respectively. The change in yellowness (b value) decreased with increases in barrel temperature, feed rate and pumpkin flour percentage.

Table 6-4 : The regression models for the product colour

Response	Model	R-squared (R2)
L	$71.47 – 4.20X_1 + 0.34X_2 – 3.76X_3$	0.5060
a	$4.60 + 0.90X_1 – 0.11X_2 + 1.37X_3 – 0.13X_1^2 – 0.092X_2^2 – 0.96X_3^2 + 0.067X_1X_2 + 0.25X_1X_3 – 0.050X_2X_3$	0.9540
b	$38.02 – 2.15X_1 + 0.45X_2 – 0.031X_3$	0.7153

The fitted regression models for bulk density (BD) and true density (TD) are shown in equations (7) and (8) respectively. Both models demonstrated linear and quadratic affects with correlation coefficients (r^2) 0.9090 and 0.9837 respectively, indicating that these models are sufficiently accurate for predicting BD and TD for the extruded product.

Bulk density = $83.70 – 20.03X_1 – 3.60X_2 + 53.48X_3 + 3.00X_1^2 + 2.89X_2^2 + 31.63X_3^2 + 3.29X_1X_2 – 23.49X_1X_3 -1.95X_2X_3$ ------------------- (7)

True density = $132.75 -26.75X_1 – 9.12X_2 + 84.67X_3 + 4.51X_1^2 + 4.36X_2^2 + 42.56X_3^2 + 10.22X_1X_2 – 37.28X_1X_3 – 6.62X_2X_3$ ---------------------- (8)

The bulk density and expansion ratio were found to have a link in terms of degree of puffing of starch, there is an inverse relationship between ER and BD, where higher ER contributed to lower BD.

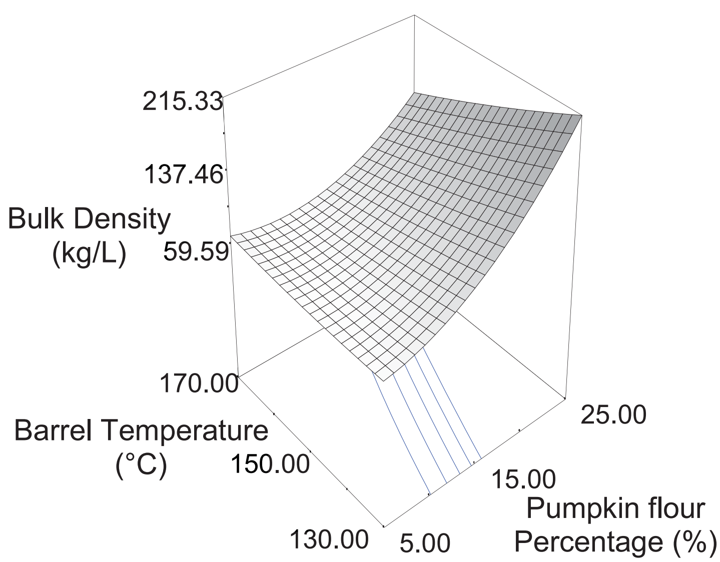


Figure 6-11 : Effect of barrel temperature, feed rate and pumpkin flour percentage on bulk density.

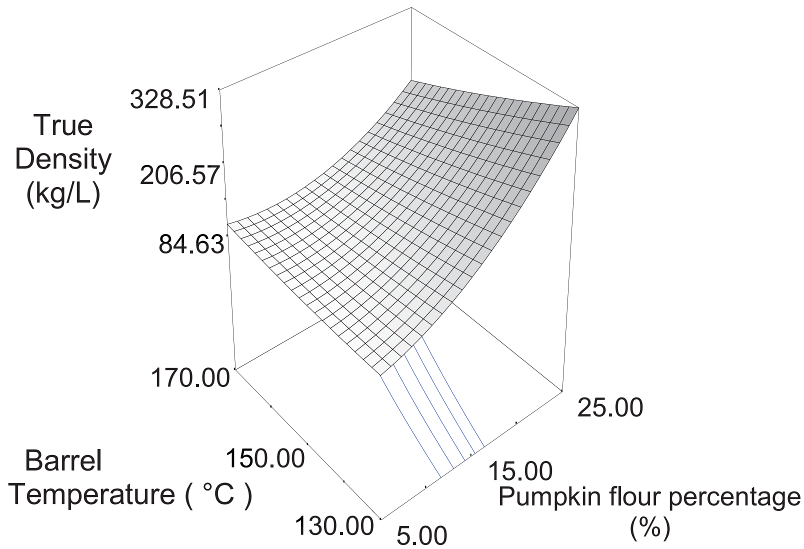


Figure 6-12 : Effect of barrel temperature, feed rate and pumpkin flour percentage on true density

The relationship between product hardness and processing parameters is described by a combination of linear and quadratic in equation 9. Hardness of the extrudate was significantly ($P<0.01$) affected by the linear and quadratic effects of all variables. The regression model (equation 9) for hardness showed a higher coefficient of determination (r^2 = 0.9638), which indicates that the model accounts for most of the observed variation in the data collected for this study. However, the model has a C.V of greater than 10% (23.14%) and a significant lack-of-fit ($P<0.01$). Therefore, the model developed for the hardness of the pumpkin flour –corn grits snack product is considered inadequate.

$$\text{Hardness} = 165.63 - 73.08X_1 - 6.62X_2 + 210.91X_3 + 8.37X_1^2 + 6.16X_2^2 + 159.25X_3^2 + 19.02X_1X_2 - 111.37X_1X_3 + 1.32X_2X_3 \quad \text{-------------------} \ (9)$$

The effect of pumpkin flour and barrel temperature on hardness is shown in the response surface plot in Figure 6-13. The maximum hardness (996.97N) at coded point (-1,0,1) was about 6.5 times greater than the minimum hardness (133.30N). The average hardness for pumpkin flour- corn grits snack products was 298.51N. The hardness was found to be proportional to the bulk density of the product with both increasing with barrel temperature (183.64°C). This is in line with studies done by Altan et al. (2008) and Ding et al., (2005). As observed, as high percentage of pumpkin flour added the final product is normally associated with a harder product structure. The results from these experiments show that the minimum hardness value of the extrudate was achieved at the highest barrel temperature (183.64°C) with 15% pumpkin flour added at 11.25kg/hr feed rate.

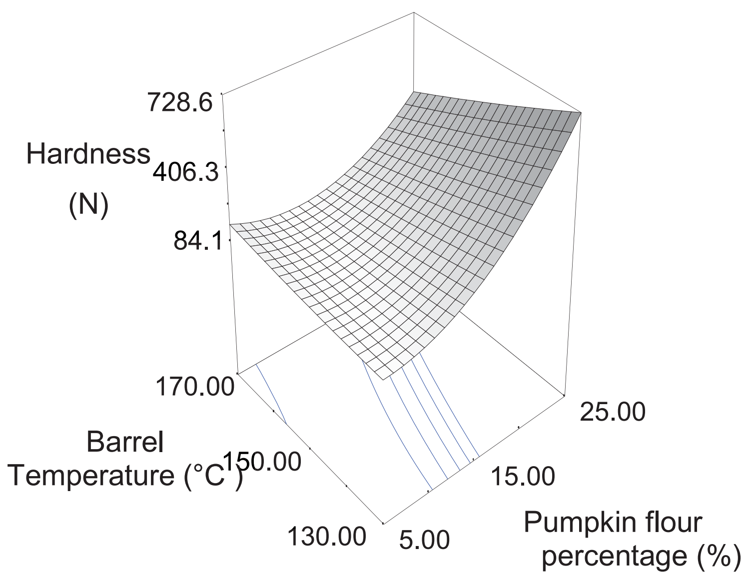


Figure 6-13 : Effect of barrel temperature, feed rate and pumpkin flour percentage on the product hardness

The total carotenoid or Vitamin A precursor in fresh pumpkin was found to decrease during the extrusion process. Product yellowness in the extruded product was mainly due to the presence of carotenoid pigment.

As expected the carotenoid content of the final product increases linearly with the concentration of carotenoid in the base formulation i.e. carotenoid content increases with pumpkin flour content. The degradation of carotenoid during processing is a combination of barrel temperature and feed rate. There was no evidence however of interactions between processing variables and carotenoid degradation. Collectively the final total carotenoid content of the extruded product may be predicted from equation 10.

Lack of fit was found not statistically significant and thus indicates that the model is adequate for prediction.

$$\text{Total Carotenoid} = 1.81 - 0.28X_1 - 0.28X_2 + 1.26X_3 \quad \text{------------------} \ (10)$$

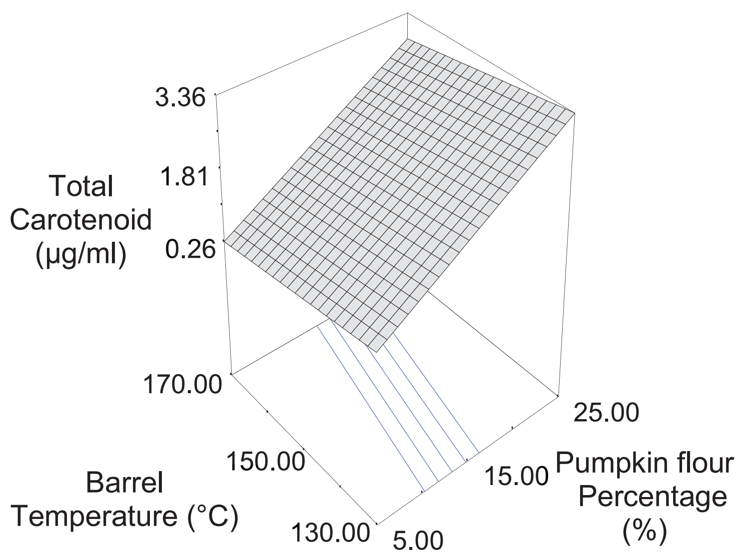


Figure 6-14 : Effect of barrel temperature, feed rate and pumpkin flour percentage on the total carotenoid

6.4 Summary of Results and Optimisation

Overall results of predicted responses were shown in **Table 6.5** below. The adequacy of the models was tested using coefficient of determination (R^2). R^2 with value more than 0.8 was considered adequate (Herika,1982).Therefore the model of responses that were found adequate were pressure thrust, sectional expansion, a value, bulk density, true density, hardness and total carotenoid.

Table 6-5 : Analysis of varience (ANOVA) for response surface for dependant variables of pumpkin flour-corn grits snacks.

Response	Lack of fit	R^2	Adjusted R^2
Power Consumption (kW)	Not significant	0.73	0.68
Torque	Not significant	0.58	0.50
Specific Mechanical Energy (SME)	Not significant	0.54	0.45
Pressure Thrust	Not significant	0.86	0.83
Longitudinal Expansion	Not significant	0.66	0.60
Sectional Expansion	Not significant	0.91	0.83
L value	Significant	0.51	0.41
a value	Significant	0.95	0.91
b value	Not significant	0.72	0.66
Bulk Density	Significant	0.98	0.97
True Density	Significant	0.98	0.96
Hardness	Significant	0.96	0.93
Total Carotenoid	Not significant	0.83	0.80

Table 6-6 : Solutions for optimum conditions and responses

No.	Barrel Temperature (°C)	Feed Rate (kg/hr)	Pumpkin flour (%)	Radial Expansion	Hardness	SME	Total carotenoid	Desirability
1	166.44	10.50	16.72	11.15	133.30	0.15	2.07	0.615
2	166.28	10.50	16.67	11.16	133.32	0.15	2.06	0.615
3	165.84	10.50	16.55	11.20	133.36	0.15	2.06	0.615
4	166.21	10.50	17.14	11.07	142.07	0.15	2.13	0.614

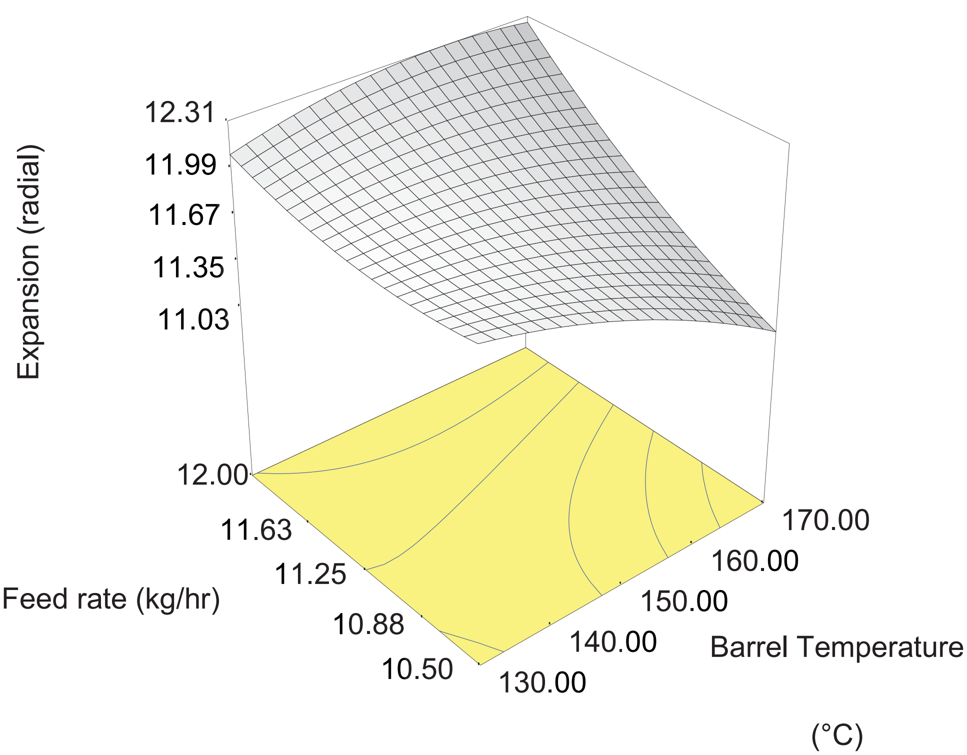


Figure 6-15 : Predicted response surface plot for the effect of feed rate and barrel temperature on radial expansion of pumpkin flour-corn grits snack.

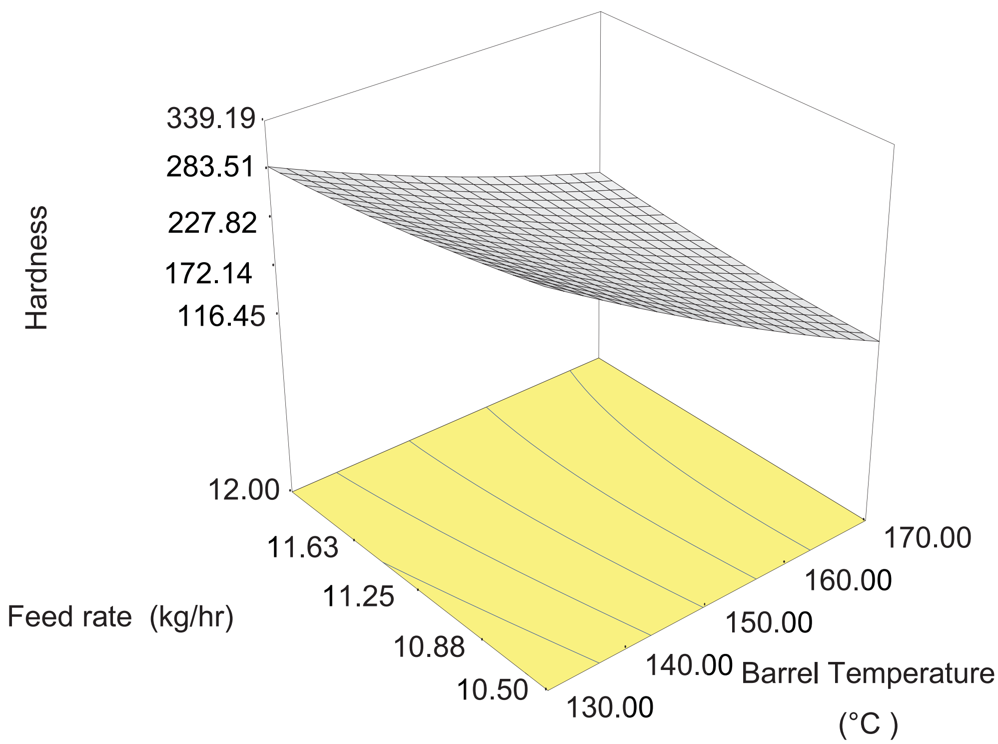


Figure 6-16 : Predicted response surface plot for the effect of feed rate and barrel temperature on hardness of pumpkin flour-corn grits snack.

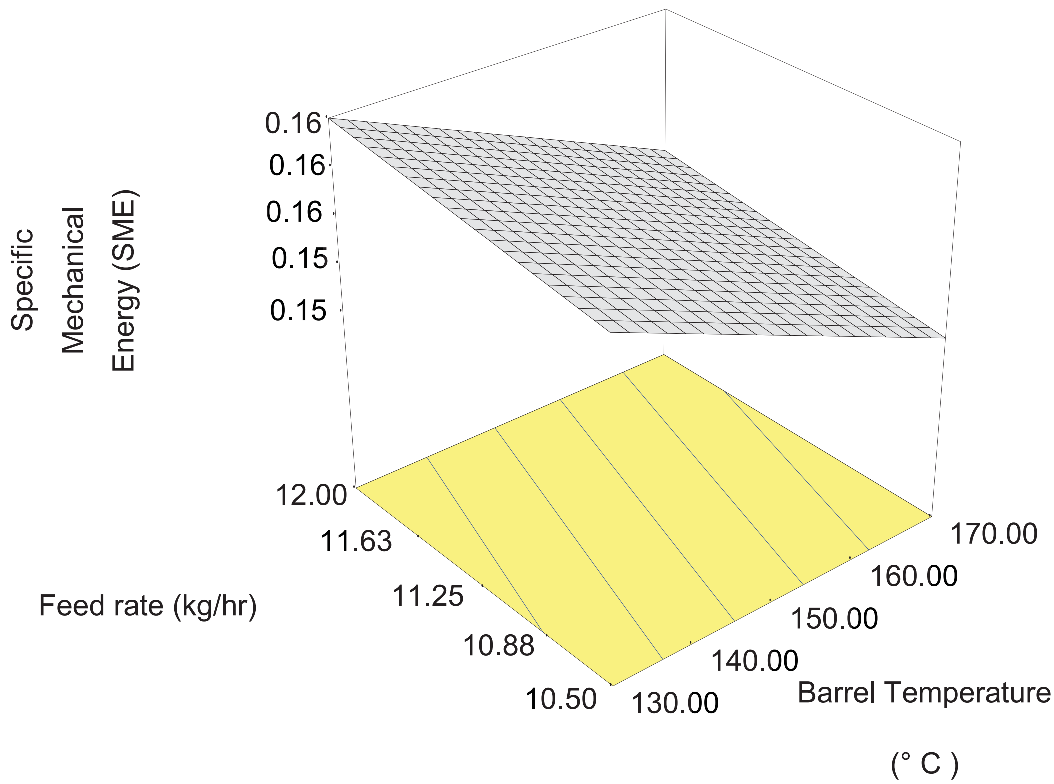


Figure 6-17 : Predicted response surface plot for the effect of feed rate and barrel temperature on specific mechanical energy (SME) of pumpkin flour-corn grits snack.

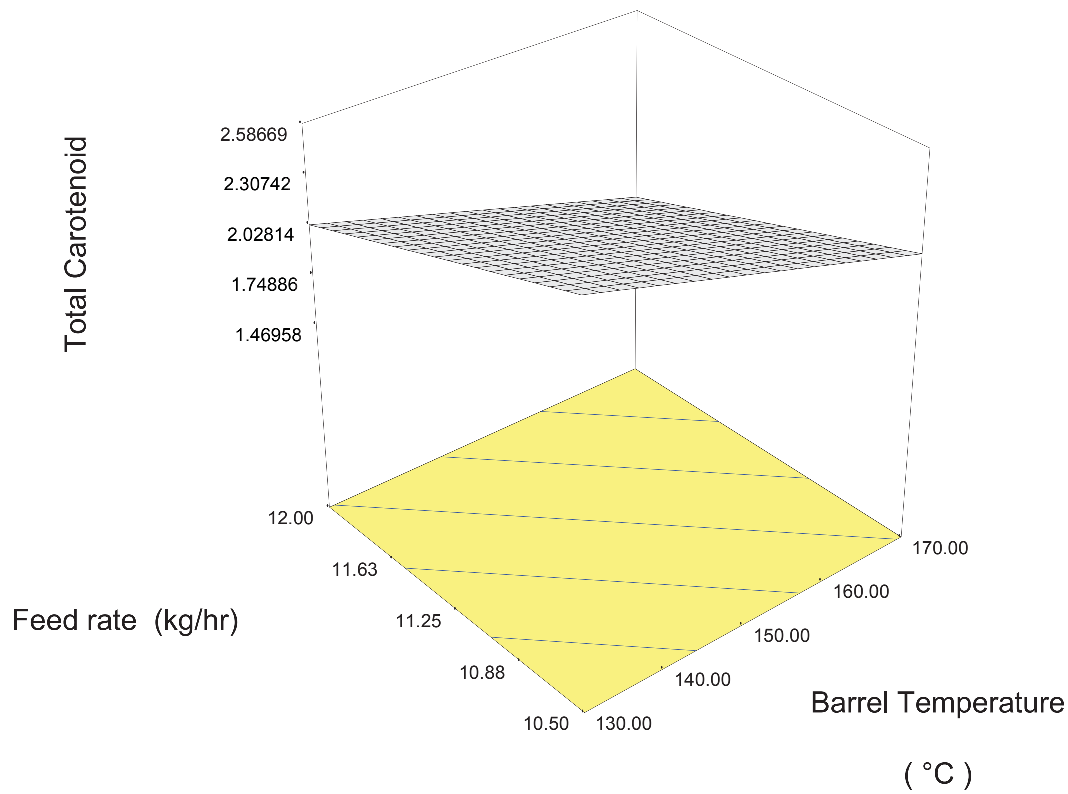


Figure 6-18 : Predicted response surface plot for the effect of feed rate and barrel temperature on total carotenoid content of pumpkinn flour-corn grits snacks.

6.5 Conclusion

Overall, the results show that all variables have a lack of fit that is not statistically significant (P>0.05), which indicate these models are suitable for predicting the effect of processing on pumpkin flour-corn grits extruded products. These models suggested that the optimum extrusion parameters are ; barrel temperature 166.51°C, Feed rate 10.50kg/hr and pumpkin flour percentage 16.73% in order to get maximum radial expansion 11.14 with lowest hardness 133.30, highest total carotenoid 2.07ppm and optimum SME at 0.15.

Chapter 7: Final Product Quality

7.1 Background

The final quality of extruded snacks is influenced by a large number of processes and variables. The focus of this thesis is on the incorporation of pumpkin flour as a potential added value ingredient in extruded snacks that may enhance their nutritional value and also may provide benefits such as contributing a good natural yellow colour to the product. The previous chapters have shown that inclusion of pumpkin flour into a traditional corn grits based formulation necessitates changes to process parameters in order to optimise production. However, during the extrusion process pumpkin flour may also undergo physical-chemical modifications, resulting in changes in nutritional value and just as importantly changes in consumer acceptance. If the snack does not deliver on nutritional benefits or results in a product that is not acceptable to consumers then the value of pumpkin inclusion is diminished. On this basis the discussion in this chapter is focused on the retention of the key nutritional benefit of pumpkin flour, carotenoid content, through processing and a sensory analysis of the final product. Additional analysis on the starch digestibility, and microstructure of the final product is also presented.

In addition to pumpkin flour possessing a high content of carotenoid pigment, which provides an orange colour to the food product, the carotenoid content is also of great interest to health-conscious consumers for its antioxidant potential. However, it is known to be unstable and sensitive to light and heat treatment. There areseveral studies on the carotenoid content of pumpkin and the effect of extrusion on the carotenoid of other fruit and vegetables (refer to **Table 7-1** below). In general, during processing, vitamin decreases with increasing temperature, increasing screw speed, decreasing moisture, decreasing throughput (i.e. longer residence time), decreasing die diameter and increasing specific energy input (Killeit, 1994). Guzman-Tello and Cheftel (1990) reported that the losses of total carotenoid during the extrusion process was due to thermal degradation and evaporation of the vitamin at the extruder outlet.

Table 7-1 : Carotenoid study done by several researchers

Research	References
Changes in carotenoids during processing and storage of pumpkin puree	Provesi, Dias & Amante (2011)
Carotenoid composition in different species and varieties of pumpkin	Kurz,Carle & Schieber.,(2008); Azevedo-Meleiro & Rodriguez-Amaya.,(2004); Murkovic,Mulleder & Neunteufl.,(2002)
Effect of extrusion on carotenoid content in cream and orange flesh sweet potato cultivars	Fonseca, Soares, Junior, Almeida & Ascheri (2008)
Effect of extrusion cooking on nutritional value –a literature review	Bjorck & Asp, (1983)

Most snack products manufactured via extrusion processing are predominantly starch-based and therefore result in energy dense products with a low nutritional value. Therefore by adding vegetable or fruit powder, high in nutrients, to the snack formulation the nutritional value may be improved. Naturally, starch gelatinisation provides unique textural and structural characteristics to the final product during food extrusion processing. Colonna, Tayler and Mercier (1989) stated that the extrusion process causes degradation of the starch and the digestibility of the starch increases in relation to the severity of the extrusion process (Bjorck, Nyaman & Asp., 1984), Moreover the gelatinisation of starch during extrusion processing will also influence the nutritional value of the extruded final product by affecting starch digestion during consumption of these products. **Table 7-2** shows the classification of starch based on its digestibility as reported by Englyst, Kingman and Cummings (1992).

Table 7-2 : In vitro nutritional classification of starch.

Starch type	Source	Digestibility in small intestine
Rapidly digestible starch (RDS)	Freshly cooked starchy foods	Rapid
Slowly digestible starch (SDS)	Most raw cereals	Slow but complete
Resistant starch (RS) Physically inaccessible starch (RS1)	Partly milled grain and seeds	Resistant
Resistant starch granules (RS2)	Raw potato and banana	Resistant
Retrograded starch (RS3)	Cooled, cooked potato, cornflakes and bread	Resistant

Structure is a key parameter to understanding the behaviour of foods and the basic mechanisms of physicochemical changes. Food structure relates to nutrition, chemical, microbiological stability, texture, physical properties, transport properties, product engineering and product texture. Therefore, the extrusion process has a considerable effect on food structure and nutritional quality of food products. The structure of the final expanded snack is developed through formation of bubbles due to moisture flashing off on exiting the extruder die and the bubbles becoming entrapped when the dough solidifies as a result of viscosity increasing due to both increases in the total solids content and evaporative cooling.

Acceptance and the successful launch of a new product, is not only dependent on the processing parameters or formulation but most importantly is dependent on the sensory evaluation of the consumer. The sensory feedback of a consumer can be a reliable tool to determine the acceptance of and preference for the product. Moreover, in defining the quality characteristics of the extruded snacks, consumer perceptions and acceptance are the most critical elements (Munoz & Chambers, 1993: Galvez & Resurreccion, 1992).

Many studies have been performed on pumpkin utilisation and usage in bread fortification (Noor Aziah & Komathi, 2009), pumpkin jam, pumpkin noodles and 3rd generation pumpkin snacks (refer to **section 2.6.1**) (Konopacka Seroczynska, Korzeniewska, Jesionkowska,Niemirowicz-Szczytt, & Plocharski, 2010). Nutritious snack foods can be made not only from cereal grain as in the commercial market, but can also incorporate other vegetables, legumes, and fruits in their formulation (Ibanoglu ., Ainsworth, Ozer, & Plunkett,2006). Second-generation snacks (direct-puffed snacks) are usually low in bulk density and there are commercially produced examples of such products that are high-fibre, high protein, contain nutritional products and are low calorie (Liu., Hsieh., Heymann., & Huff., 2000). Currently, there are limited studies on the effect of extrusion cooking on the carotenoid content, starch digestibility and sensory evaluation of pumpkin flour and corn grits expanded snacks.

This chapter focuses on four (4) main factors affecting the final quality of the extruded pumpkin-corn grits snacks product; Total β-carotene content, starch digestibility, microstructure and sensory evaluation.

7.2 Materials and Methods

The five best formulations of the 20 pumpkin-corn grits snack products analysed in earlier chapter (**Chapter 6**) were selected for carotenoid determination, starch digestibility analysis and sensory evaluation including consumer acceptance and preference. The selection was based on the highest expansion ratio, highest pumpkin level, the least hardness and the lightness and yellowish-brown colour of the expanded snack product.

7.2.1 Extrusion Conditions

Extrusion parameters and formulation were used as described in **6.2.1. Table 7-3** shows the formulation and extrusion conditions for producing the pumpkin flour-corn grits expanded snacks.

Table 7-3 : Formulation and extruder conditions

Sample	Barrel Temperature (last 3 barrel) (°C)	Mass flow (kg/hr)	Label
15% Pumpkin Flour + 85% Corn grits	150	12.5	15%PF,BT 150,MF 12.5
15% Pumpkin Flour + 85% Corn grits	150	10.0	15%PF, BT150, MF 10.0
5% Pumpkin Flour + 95% Corn grits	130	12.0	5%PF,BT 130, MF 12.0
100% Corn grits	150	11.3	Control (100% corn grits)BT150, MF11.3
5% Pumpkin Flour + 95% Corn grits	170	12.0	5%PF, BT 170, MF 12.0

7.2.2 Total Carotenoid Analysis

Extraction of total carotenoid in pumpkin and pumpkin based extruded product was carried out as described in **section 6.2.5** and standard curve of total carotenoid in Appendix 3.

7.2.3 Starch Digestibility

In vitro starch digestibility was carried out using the method of Englyst., Veenstra., andHudson (1996) and Brennan, M., Merts., Monro., Woolnough., and Brennan,C (2008). A 2.5g ground sample (<4.75mm) was mixed with 30ml of deionised water, then 1 ml of 1M hydrochloric acid (HCL) and 1 ml pepsin (10% solution in 0.05M HCL) were added and the digestion was carried out at 37C for 30 minutes with a slow constant mixing. Then 2 ml NaHCO3 (1M), 5 ml,0.1M Na Maleate buffer (pH6) and 5 ml pancreatin (2.5% in 0.1M Na maleate buffer, pH 6) were added for further digestion. 0.1ml amyglucosidase (MegaZyme E-AMGDF) was added to prevent end product inhibition of pancreatic amylase and the total volume adjusted to 55 ml. The samples were further incubated at 37°C with slow constant mixing (130rpm)for 120rpm. A duplicate of 1 ml aliquots of the mixture was collected at 0,20, 60 and 120 minutes and added to 4 ml ethanol (95%w/v) to stop the digestion process and prepare for determination of reducing sugar content using 3,5-dinitrosalicylic acid methods.

The amount of starch digestion was determined by comparing the absorbance of the sample to a glucose standard curve. Rapidly digestible starch (RDS) is the starch that hydrolysed within the first 20 minutes of incubation while slowly digestible starch (SDS) was identified the starch hydrolysed between 20 and 120 minutes of digestion.

7.2.4 Proximate Composition

Proximate composition for all samples was determined as described in **section 3.2.3**.

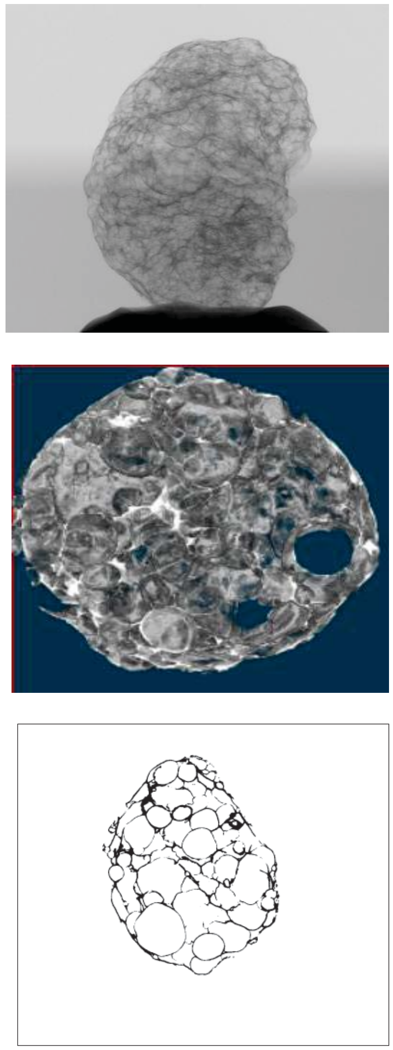
7.2.5 Sensory Evaluation

The main objectives of sensory evaluation in this study were to determine product acceptance and preference of the pumpkin-flour –corn grits expanded snack product. The panelists were also asked to rank the product from the least liked to the best liked.

Forty (40) panellists comprising 14 males and 26 females aged between 19 to 64 years, were randomly recruited among staff and students of the Institute of Food Nutrition and Human Health, Massey University, Palmerston North, New Zealand, to evaluate the extruded product without any knowledge of the formulation or the product. The panellists were asked to evaluate the overall acceptability, colour, smell, product’s texture, taste, pumpkin flavour intensity, and potential of buying this product as a snack using a structured nine-point hedonic scale (Stone & Sidel, 2004). The sensory evaluation was conducted in the sensory lab equipped with 10-individual partitioned booths. Drinking water was provided to clean and rinse the mouth between samples. The samples were place in shallow white cup and were coded using a random three-digit number. They were served under normal lighting conditions at room temperature (25°C).

7.2.6 Microstructure of Expanded Snack Product

The extruded product was imaged using X-ray microtomography (Skyscan, Kartuizersweg 3B, 2550 Kontich, Belgium). Image acquisition was carried out using an x-ray beam energy of 60kv at a current of 160µ and images were recorded using a pixel size of 17.1 µm and an image size of 2000 × 1048 pixels. The sample was scanned for 180° of rotation at intervals of 0.4° of rotation. Three dimensional (3D) images were reconstructed using NRecon software provided with the machine from which a series of 180-200 vertical slices, each 3 μm thick were generated. A grid of 81 points using ImageJ software (Version 1.43) was overlaid on the image and the number covering the image was manually counted. The number of points falling on voids was calculated as the void volume (%) as a proportion of the number of points covering the image.



Extruded pellet mounted on imaging stub

3D image of expanded snack

2D image of expanded snack

Figure 7-1 : Summary of the process of how the microstructure of the expanded snack was captured and analysed

7.3 Results and Discussion

7.3.1 Total Carotenoid Content

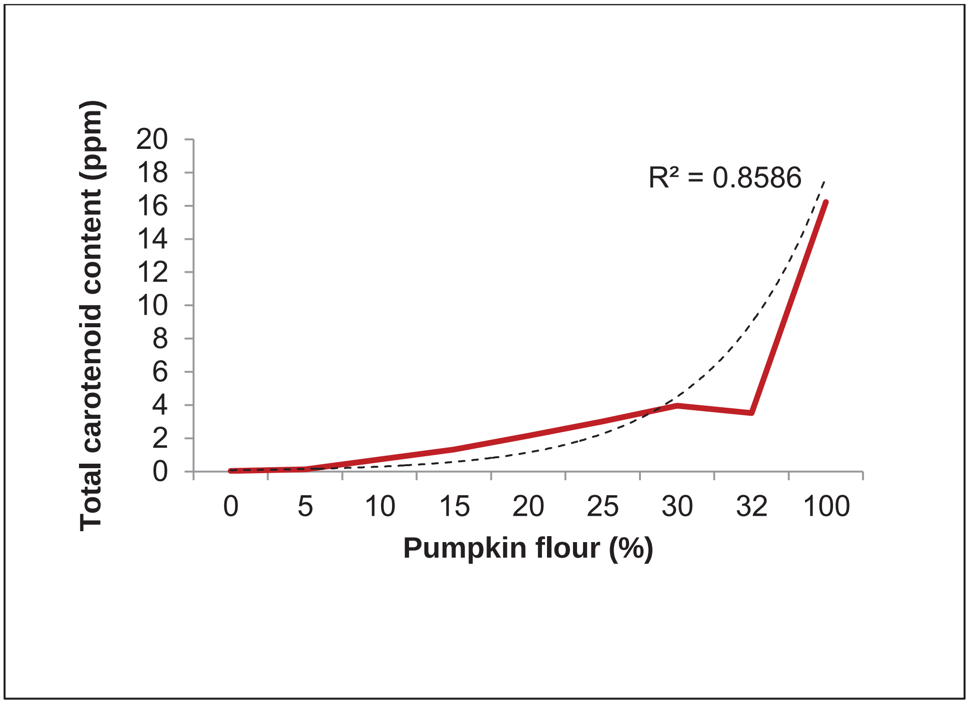


Figure 7-2 : Total carotenoid content of raw materials (unextruded)

Figure 7-2 shows the total carotenoid content in unextruded materials at different percentage levels of pumpkin flour. The carotenoid content is expressed as ppm. Overall, the results show low carotenoid values in both unextruded and extruded product. For most carotenoid studies, the significant value of carotenoid present must be more than 2 ppm in any sample. The values presented in the figure above seem too low and it was suspected that insufficient extraction for each sample may possibly have reduced the measured carotenoid level. A second possible explanation for the low levels measured is that the method used did not have a prior separation. The highest carotenoid content was shown in pumpkin flour (16.22ppm) and almost nil in corn grits.

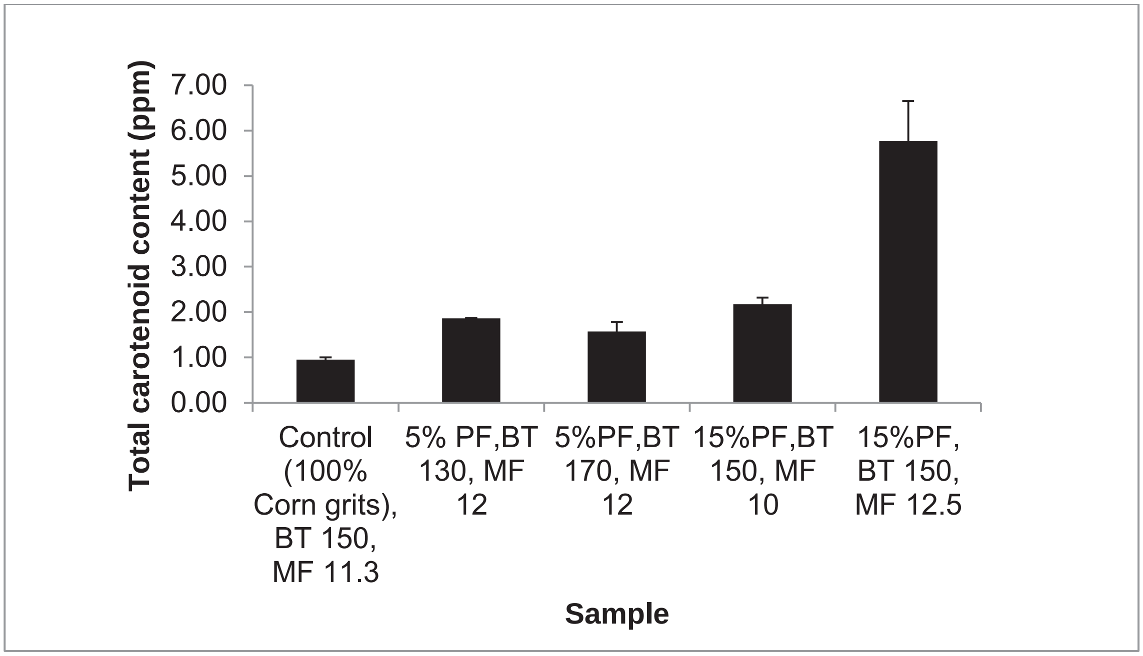


Figure 7-3 : Total carotenoid level (ppm) in pumpkin flour-corn grits snacks at different level of pumpkin flour added, different barrel temperature (°C) and different mass flow (kg/hr)

As observed in **Figure 7.3** the carotenoid value in the extruded product was found to be higher than in raw materials. This provided evidence that inclusion of pumpkin flour in extrusion cooking increases the extractability of the carotenoid content. This is in agreement with Harper., Stone., Tribelhorn., Jansen., Lorenz., and Maga (1977) who suggested that extrusion cooking improves the extractability of vitamin A. Moreover a study done by Dehghan-Shoar, Hardacre, Meerdink, & Brennan (2011) showed that this phenomenon was due to incomplete mechanical and thermal degradation of carotenoid during extrusion that may affect the uptake by the cells.

Table 7-4 : Pearson's correlation of total carotenoid

	Formulation	Barrel Temperature	Feed rate	Total carotenoid content
Formulation	1			
Barrel temperature	0.22	1		
Feed rate	0.06	0	1	
Total carotenoid	0.65	-0.02	-0.69	1

The pearson correlation (**Table 7-4**) showed a strong positive relationship between measured carotenoid content and formulation (R^2=0.65), showing increases in total carotenoid content with increases in pumpkin flour content. Moreover, the result indicates that the total extractable carotenoid content is higher in the extruded snack compared to the initial carotenoid content. However, a negative correlation was found between feed rate and carotenoid content (r^2=-0.69), at a lower feed rate the total carotenoid increased. This finding contradicted a study done by Fonseca, Soares,Freire Junior,Almeida, and Ascheri., (2008) which found that lower feed rates decreased the carotenoid content in sweet potato due to long retention in the barrel which melt the viscosity.

Killeit (1994) reported that the initial all-trans β-carotene was destroyed by 38-73% at barrel temperatures between 125° - 200°C. Jansen (1979) found that retention of vitamin A ranged between 87-100%. Even though there were several studies on the carotenoid analysis on pumpkin, extrusion process but the published works on the carotenoid content of unextruded and extruded product made from pumpkin and corn grits are limited references.

7.3.2 Starch Digestibility

The digestibility of starch fractions of the raw material prior to extrusion and of expanded snacks made from pumpkin flour-corn grits was measured using the Rapidly Digestible Starch (RDS) and Slowly Digestible Starch (SDS) methods. Results are shown in **Figure 7-4** below. In a previous study, the extrusion processing resulted in a significant increase in starch digestibility due to gelatinisation of the starch in the extruded product compared to the unextruded raw materials (Hagenimana et al., 2006). In contrast our study indicates the opposite. A potential mechanism that would explain the current results is that interactions with other components in particularly sugar and pectin components from the pumpkin flour, which trap starch granules within a viscous pectin-starch network, such entrapment would be expected to hinder in vitro digestion due to reducing contact between digestive enzymes and starch. This result supports the theory presented by Altan et al., (2009) and Hagenimana et al.,(2006), who found that starch digestibility was lower in barley-based extruded products. In addition to the entrapment mechanism mentioned above, Altan et. al., (2009) also conjectured that a second mechanism is at work. They postulated that there may be incomplete rupturing of starch granules (i.e. gelatinisation) resulting in limited enzyme access during the digestion and hence slower amylolytic hydrolysis. Other factors that significantly contribute to lower starch digestibility that have been identified by researchers include; amylose-amylopectin ratio (Lai et al., 2000), starch-protein interactions and granule particle size (Englyst et al., 1992; Hoover and Sosulski, 1985).

Extrusion conditions such as barrel temperature, screw speed and feed moisture content may also alter the digestion of starch (Yagci & Gogus, 2010). The strong positive relationship (r^2=0.85) between barrel temperature and RDS as well as between formulation and SDS (R^2=0.88) were observed in Table 7-5 Pearson's correlation. Increased barrel temperature resulted in an increase in starch digestibility, this result is in line with Chiang and Johnson, (1977).

RDS and SDS are indicative of the rate of carbohydrate release (starch digestion) from foods into blood sugar (absorption) and generally reflects the glycaemic response (Englyst & Hudson, 1996).

The RDS of pumpkin flour – corn grits snacks ranged from 35.00 to 40.15 mg/g and the SDS ranged from 43.71 to 97.03mg/g. The overall value of RDS was lower than SDS for all of the pumpkin flour-corn grits expanded snack formulations. The variation in RDS between the formulations was not statistically significant ($P>0.01$). In contrast the relationship between formulations (i.e. level of pumpkin flour incorporation) and SDS values were statistically significant ($P<0.01$).

RDS is a starch fraction that causes a rapid increase in blood glucose levels after ingestion while SDS is a starch fraction that slowly digests resulting in the gradually release of sugar and hence smooth, stable rises in blood sugar (Chung, Liu & Hoover, 2009).Therefore SDS may become a nutritionally favourable option for snack manufacturer who wish to produce healthy snacks for the consumers.

High SDS values were obtained under the following process conditions: barrel temperature of 150°C, feed rate of 12.5kg/hr and 15% pumpkin flour inclusion. In contrast a snack manufactured under the same conditions but with no pumpkin flour added resulted in low value of SDS for pumpkin-corn grits expanded snack products.

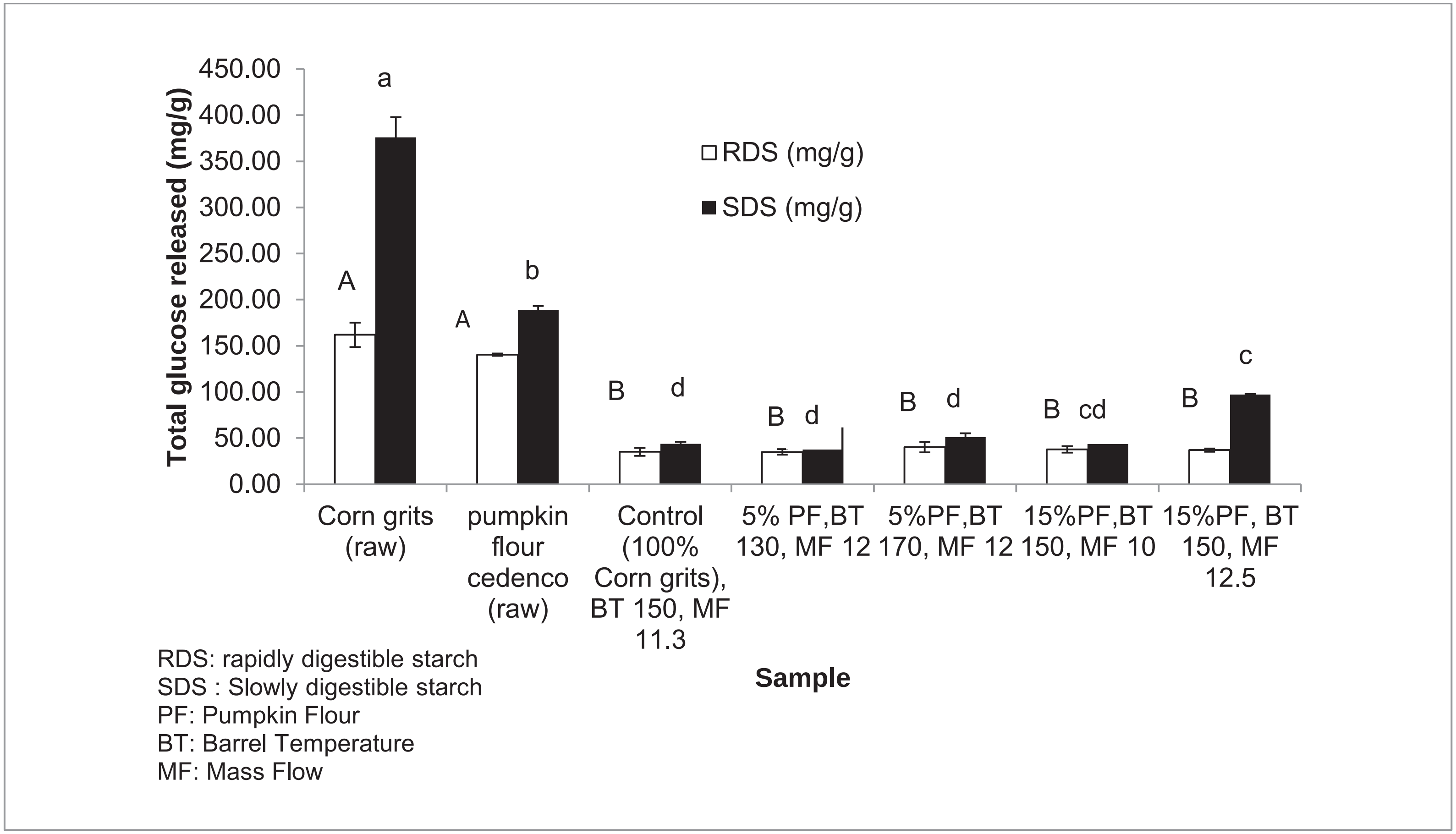


Figure 7-4 : In vitro starch fractions of raw materials (unextruded) and extruded pumpkin flour-corn grits snack products

Table 7-5 : Pearson's correlation of extruded pumpkin flour-corn grits snacks

	Sample	Barrel Temperature	Mass Flow	RDS	SDS
Sample	1				
Barrel temperature	0.22	1			
Mass Flow	0.06	0	1		
RDS	0.48	0.85	-0.03	1	
SDS	0.88	-0.18	0.25	0.04	1

Table 7-6 : Pearson's correlation of unextruded (raw materials) and extruded pumpkin-corn grits snacks

	Sample	RDS	SDS
Sample	1		
RDS	-0.79	1	
SDS	-0.68	0.93	1

7.3.3 Pearson's Correlation of Proximate Composition

The correlation of pumpkin flour inclusion on the proximate composition of the expanded snack is given in **Table 7-7** below.

Table 7-7 : Pearson's correlation of proximate composition in pumpkin flour-corn grits expanded snack

	sample	*moisture*	*ash*	*fat*	*protein*	*CHO*
sample	1					
moisture	-0.71	1				
ash	0.94	-0.51	1			
fat	0.71	-0.91	0.58	1		
protein	0.16	-0.27	0.22	0.64	1	
CHO	-0.60	0.53	-0.63	-0.83	-0.89	1

Pumpkin flour – corn grits snack products contain moisture ranging from 7.34-7.81%, while snack products made from 100% corn grits were found to contain higher moisture (8.46%) than the other samples. As increased of pumpkin flour inclusion increased of protein content and no significant loss of carbohydrate was found during the extrusion process.

7.3.4 Sensory Evaluation

The data presented in this section has been interpreted using the scale reported by Knuckles, Hudson, Chiu and Sayre. (1997) Product attributes with a mean score greater than 5 were considered to be positive or liked by the consumer. While sensory attributes falling below 4 were deemed unacceptable by the panellists. The mean score of sensory attributes for the pumpkin flour-corn grits snack products is given in Table 7-8. There was no significant difference ($P>0.001$) in terms of the overall acceptability, smell of the food, texture and taste of the food detectable by the panellists. The colour of the snack products was however detected by panellists and this data was correlated in terms of acceptability with the level of pumpkin flour in the formulation ($P<0.001$).

The mean panellists' scores for colour acceptability ranged between 4.63 ("dislike slightly") to 7.00 ('like moderately"). By inspection it can be seen that the snack containing 5%pumpkin flour extruded at a barrel temperature of 130°C with a feed rate of 12kg/hr gave the best score for the colour acceptance(mean score= 7.00). The panellists were found to moderately like the snack with a light yellow-brown product colour compared to the snack with 15%pumpkin flour inclusion, which showed very low acceptability by the consumers who based on their comments associated the colour of snacks containing higher levels of pumpkin flour with being burnt.

The panellists were able to distinguish at a level of significance of P<0.001, all the samples on the basis of product colour. A degradation of carotenoid pigment and maillard reaction due to high sugar content in the pumpkin flour are likely to have caused the undesirable darker and burnt colour of the product that resulted in the panellists designating the colour unappealing. This result was in agreement with Pongjanta, Naulbunrang, Kawngdang, Manon and Thepjaikat.(2006) who found that the colour values of products increased with higher inclusion of pumpkin flour and thus resulted in a decrease in acceptance of the products .While the raw data indicates that panellists were found more likely (mean score = 6.03) to prefer the smell of snacks extruded with 0% pumpkin flour added compared to the snack products with pumpkin flour inclusion (mean score ranged from 5.56 to 6.00) a statistical analysis showed that there was no significant difference between the samples (P>0.001). It was suspected that the panellists preferences might be partially due to familiarity with the smell of corn snack products through availability in the market. The undesirable smell detected by panellists may in part be due to pyrolysis resulting from the high levels of sugar in pumpkin flour.If this is the case then it may be possible to manipulate processing to minimise to a certain extent, the degree of Maillard reactions via temperature manipulation.

Texture in extruded snacks plays an important role in sensory quality. The definition of texture from a sensory perspective can cover a broad range of characteristics that include the molecular structure of the food and it also how a food is perceived when touched and pressed (Szcesniak, 2002).

In this study, texture refers to the hardness of the snack that is detected by panellists based on mechanical forces when compressing the snack between molar teeth. Terms that may be used to describe the product by panellists include soft, firm and hard.

However, some of the consumers based on their comments distinguished products based on textural characteristics such as stickiness (adhesiveness). The highest mean score of texture likeness (mean score=6.75, “like slightly” to “like moderately”) was observed on the snack with 5% pumpkin inclusion cooked with a barrel temperature of 170°C with a 12kg/hr feed rate.

Added pumpkin flour in the snack processing was anticipated to contribute sweet, sour and bitter tastes to the end product. Sweet tastes in products have been reported to be associated with the presence of sugar and carotenoid content (Marek et al., 2008).The mean score for liking the product in this study, with regard to taste ranged from 5.12 to 5.68. However, even though the mean score for sweetness indicates a positive liking the product taste as a whole had a low preference. This result was probably due to a lack of seasoning added to the samples. If this is true then the overall taste preference could be improved by matching the intrinsic sweetness of the pumpkin product with flavours that are typically associated with sweetness.

The overall acceptability result showed that panellist “slightly accepted’ pumpkin flour-corn grits expanded snack product as shown by mean scores ranging from 5.33 to 6.08. Curiously the panellists could not differentiate the presence or absence of pumpkin flour on the basis of pumpkin flavour in the product as they could perceived a “pumpkin flavour” in the 100% corn grits formulation. Most of the panellists perceived the taste of pumpkin in snacks including pumpkin flour in at 5% to 15% as “slightly - moderately low.

Based on a mean score of 5.30, the panellists probably would buy a snack product containing 5% pumpkin flour with extruder conditions run at barrel temperature 170°C and mass flow of 12.0 kg/hr. Based on Pearson’s correlation, taste, texture, smell and overall acceptability of the product influenced their decision to buy the snack product.

Table 7-8 : Mean scores for sensory attributes of pumpkin flour – corn grits snack products

Sample	Barrel Temperature (°C)	Mass Flow (Kg/hr)	Colour	Smell	Texture	Taste	Overall acceptability	Pumpkin flour intensity	Buy as a snack food
Control (100% Corn Grits)	150	11.3	6.77 ± 1.72^{b}	6.03 ± 1.39^{b}	6.71 ± 1.75^{b}	5.64 ± 1.80^{a}	6.05 ± 1.58^{b}	2.85 ± 1.69^{a}	4.62 ± 2.11^{a}
5% Pumpkin Flour	130	12	7.00 ± 1.40^{b}	5.63 ± 1.33^{a}	5.56 ± 1.80^{a}	5.12 ± 1.72^{a}	5.64 ± 1.70^{a}	3.10 ± 1.73^{a}	4.17 ± 2.14^{a}
5% Pumpkin Flour	170	12	6.60 ± 1.65^{b}	6.00 ± 1.41^{b}	6.75 ± 1.74^{b}	5.68 ± 1.83^{a}	6.08 ± 1.62^{b}	3.78 ± 1.79^{b}	5.30 ± 2.21^{b}
15% Pumpkin Flour	150	10	4.63 ± 2.20^{a}	5.63 ± 1.53^{a}	6.46 ± 1.92^{b}	5.53 ± 2.12^{a}	5.33 ± 2.07^{a}	4.75 ± 2.23^{c}	4.63 ± 2.53^{a}
15% Pumpkin Flour	150	12.5	5.43 ± 1.87^{a}	5.56 ± 1.57^{a}	5.80 ± 1.96^{a}	5.43 ± 1.82^{a}	5.48 ± 1.91^{a}	4.47 ± 1.91^{c}	4.53 ± 2.26^{a}

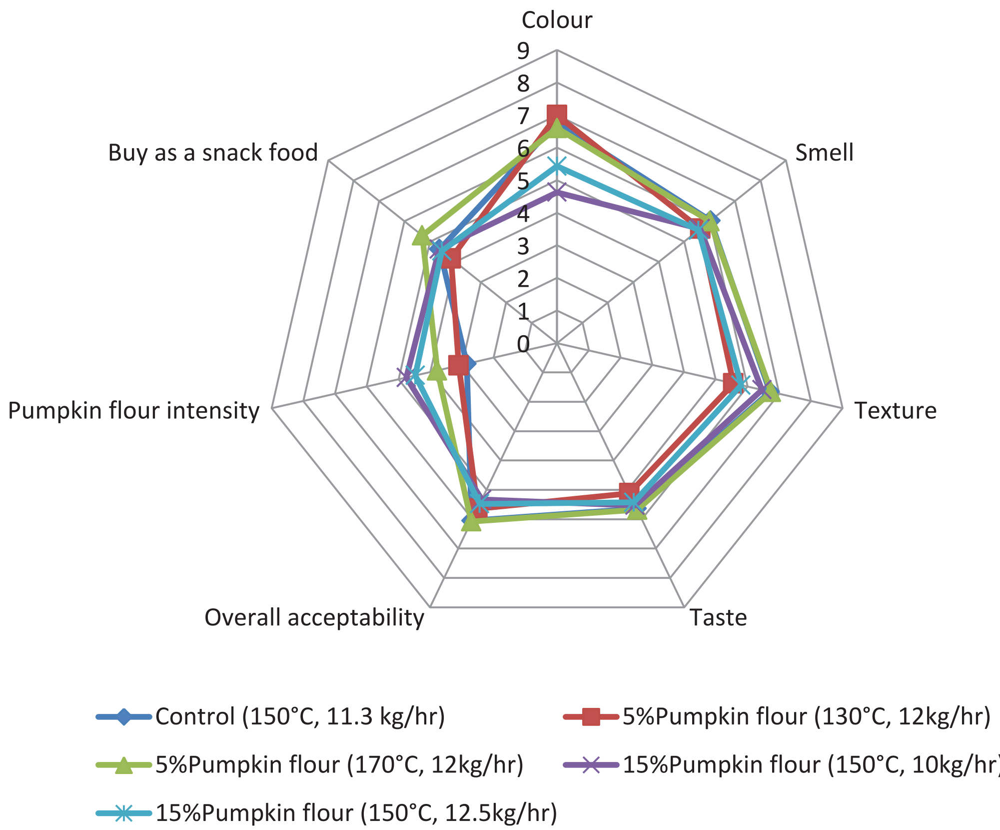


Figure 7-5 : Spider web of mean scores for sensory attributes of pumpkin flour-corn grits expanded snacks

Acceptance and preference of sensory attributes of pumpkin flour- corn grits expanded snacks was shown in **Figure 7-5** above.

Table 7-9 shows the Pearson correlation for all sensory attributes. Overall acceptability was influenced by pumpkin flour percentage (r^2=-0.68), Colour of the product (r^2=0.78), smell of the product (r^2=0.94) and texture of product (r^2=0.56). Consumers would want to buy this product based on ; taste (r^2=0.83), texture (r^2=0.78), smell(r^2=0.64) and overall (r^2=0.54).The colour of the product was found negatively correlated with the pumpkin level (r^2=-0.79) while barrel temperature was found to influence smell (r^2= 0.58), texture (r^2= 0.77) and taste (r^2= 0.88).Pumpkin flour intensity was positively correlated with the level of Pumpkin flour added (r^2=0.93). While consumers did detect pumpkin flavour in the control snacks, most consumers could distinguish the level of pumpkin flour in the product via flavour, and they could predict the right intensity of pumpkin flour in each formulation.

Table 7-9 : Pearson's correlation of sensory attributes

	Sample	Barrel Temperature	Mass Flow	Colour	Smell	Texture	Taste	Overall acceptability	Pumpkin flour intensity	Buy as a snack
Sample	1									
Barrel Temperature	0.22	1								
Mass Flow	0.07	0.00	1							
Colour	-0.79	-0.14	0.53	1						
Smell	-0.66	0.58	-0.01	0.56	1					
Texture	-0.27	0.77	-0.45	-0.03	0.81	1				
Taste	-0.01	0.88	-0.27	-0.17	0.70	0.93	1			
Overall acceptability	-0.68	0.46	0.32	0.78	0.94	0.56	0.48	1		
Pumpkin flour intensity	0.93	0.29	-0.29	-0.93	-0.57	-0.04	0.15	-0.71	1	
Buy as a snack	0.11	0.98	0.00	-0.01	0.64	0.78	0.83	0.54	0.19	

7.3.5 Microstructure of Expanded Snack Product

Due to cost restraints, micro computerised axial tomography (mico-CAT) was only carried out on the extruded product made using the 250rpm screw speed. The proportion of the cross-sectional area of the extruded pellets that was represented by void area (bubbles) for pellets containing different proportions of pumpkin flour is shown in figure 9. Near the ends of the pellets, the void area was between 50% and 60% and about 10% less than in the centre of the pellets (Dark shading **Figure 7-6** and **Table 7-10**). Towards the centre of the pellets the bubbles increased in size and the void area increased. Increasing the proportion of pumpkin flour in the ingredients although resulting in increased hardness and density of the pellets, had a relatively small effect on the proportion of void area in the pellets. The mean void are area decreased by about 15% for the ends and centre of the pellets as the proportion of pumpkin flour in the ingredients increased. However these differences in void area were not significant, although they were consistent with the significant increases in density and hardness for pellets extruded at 250 rpm.

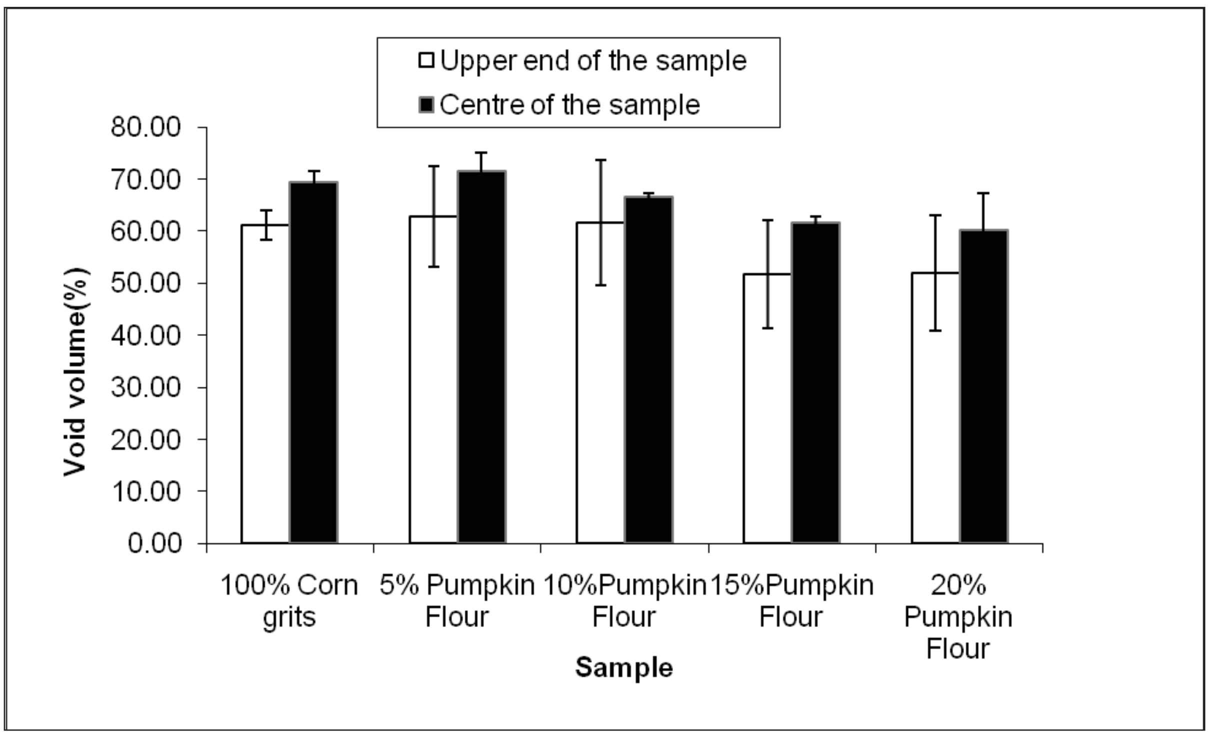
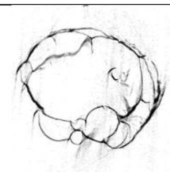
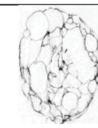
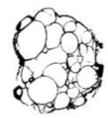
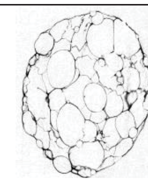
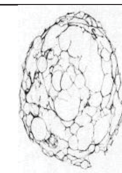
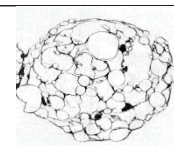
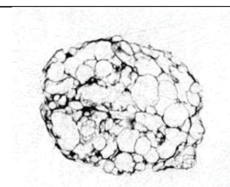
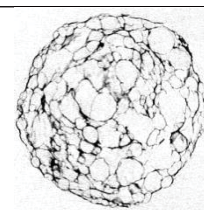


Figure 7-6 : Effect of varying pumpkin flour at constant screw speed (250rpm) on bubble area distribution at the upper end and centre of the extruded expanded snack

Table 7-10 : X-ray tomography cross sectional of 2-D image (radial): Changes of bubble size through out the extruded sample at screw speed 250rpm (Scale 1:2)

Sample	Upper end	Middle
100% Corn grits		
5% Pumpkin Flour		
10% Pumpkin Flour		
15% Pumpkin Flour		
20% Pumpkin Flour		

7.4 Conclusion

Sensory results showed that pumpkin flour could be successfully incorporated up to 5% with the corn grits to obtain an acceptable snack in terms of texture, taste, overall acceptability and potential for consumers to buy as a snack. However, in terms of nutritional value specifically the total carotenoid content, starch digestibility and proximate composition the best product quality was shown by the expanded snack product that was extruded at barrel temperature of 150°C with mass flow rate of 12.5 kg/hr. This had the highest total carotenoid (5.78ppm) with the SDS value of 97.03mg/g. This product was also found to have protein content of 28.8% with average value of moisture content (7.56%), ash (1.65%) and 59.29% carbohydrate.

Chapter 8: Overall Conclusion, Limitations and Further Research

8.1 Overall Conclusion

The objective of this research was to process all pumpkin fractions into powder then use this product as an ingredient in extrusion processing. The objective was then to develop an acceptable expanded snack product with a good flavour and texture. Moreover, it could help the food processing industry to dramatically reduce waste during processing. Cedenco Food Ltd was struggling to reduce pumpkin waste to below 25% of the harvested crop. Adding vegetable powder made from the entire fruit and not only the flesh in extrusion processing was not common. With its natural sweetness and colour, pumpkin powder could give a new option for the healthy snack food market while offering new opportunities to the pumpkin industry.

Overall this research successfully developed a new snack formulation for extrusion processing. Conditions including processing temperature, screw speed, mass flow rate and cutter speed were defined. Product properties in terms of expansion, density, hardness, colour and nutritional value including carotenoid content and starch digestibility were reported. Consumer acceptance of this snack indicated that it has potential as a commercial snack food.

The following point emerged from this work :

- The production of pumpkin flour made from entire pumpkin was found to be feasible. However, the processing of pumpkin seed for extruded snack may need treatment to reduce the oil content. Processing as a dry powder with a long shelf life, will make pumpkin flour available throughout the year.
- Although freeze drying was found to be the most effective method for drying and best conserved the nutritional value and colour of pumpkin flour, it was not commercially viable due to the high cost.
- The results obtained from this research shows that pumpkin flour is suitable for extrusion cooked snacks when blended with corn grits due to its low starch (7%) and high sugar (37%) content. The sugar and pectin content of pumpkin flour was the likely cause of the lower viscosity compared to corn grits flow when the pasting profile was assessed. The low starch content of the pumpkin reduced expansion of the snack product.

- Prediction using RSM showed the best conditions for processing pumpkin on this equipment were at a barrel temperature of 166.5°C with a feed rate of 10.50kg/hr.
- Overall, the unflavoured product was neither liked nor disliked by the sensory panellists. It is therefore, probable that the product can be flavoured to suit the intended market.
- Snack products containing 15% pumpkin flour had a protein content of 29% and carotenoid content of 13.18ppm. Slowly digestible starch (SDS) was found significantly ($P<0.01$) increased as pumpkin flour in the formulation was increased, this may contribute to lower blood glycemia. However, this may be susceptible to increase shear and temperature during extrusion.
- The improved protein and carotenoid content of these snack products may have sales advantages compared to other snacks available in the market place.

8.2 Limitations and Recommendations

This work has shown that there is no significant functional difference between pumpkin flours manufactured via freeze drying or air drying. The work did show that colour retention in freeze dried flour is much greater than air drying. However, due to the low margins associated with snack foods, as a low cost, high volume product, it is recommended to use air drying as freeze drying is both an energy intensive process and is also a batch process and thus unsuited to large volumes.

As pumpkin flour blended with corn grits gave a dark colour and burnt taste to the snacks, studies using other cereal -based ingredients should be carried out

The extruder processing conditions used only the two screw speeds and mass flow rates. Therefore, investigation of the effect of other process settings is suggested with the objective of reducing colour and burnt tastes.

Sensory results revealed that consumers preferred the expanded snack food that had lower percentage of 5% pumpkin flour. Flavouring and seasoning will improve taste and improve consumer appeal.

8.3 Further Research

Future research recommendations are as follows:

Packaging and storage study of the expanded snacks needs to be carried out.

Finally, scaled up production and marketing research are essential to confirm the demand and acceptance for this expanded snack in the real market place.

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Appendices

Appendix 1

The regression equations for the dependent variables

	KW	T	PT	SME	LE	SE	L	a	b	BD	TD	H	TC
Intercept	1.87	7.79	69.22	0.16	22.28	12.22	71.47	4.60	38.02	83.70	132.75	165.63	1.81
X_1	-0.088	-0.44	-11.30	-6.0246E-003	1.59	-0.26	-4.20	0.90	-2.15	-20.03	-26.75	-73.08	-0.28
X_2	0.12	0.56	3.14	1.714E-003	0.93	0.36	0.34	-0.11	0.45	-3.60	-9.12	-6.62	-0.28
X_3	7.622E-003	-6.957E-003	2.53	-7.722E-003	-0.64	-2.14	-3.76	1.37	-0.031	53.48	84.67	210.91	1.26
X_1^2						-0.11		-0.13		3.00	4.51	8.37	
X_2^2						0.12		-0.092		2.89	4.36	6.16	
X_3^2						-0.86		-0.96		31.63	42.56	159.25	
X_1X_2						0.27		0.067		3.29	10.22	19.02	
X_1X_3						0.47		0.25		-23.49	-37.28	-111.37	
X_2X_3						-0.056		-0.050		-1.95	-6.62	1.32	

X1-Barrel temperature, X2-Feed rate, X3-Pumpkin flour percentage, KW-Power consumption, T-Torque, PT-Pressure Thrust, SME-Specific Mechanical Energy, LE-Longitudinal Expansion,SE-Sectional expansion, L-lightness value, BD-Bulk density, TD-True density, H-Hardness, TC-Total Carotenoid

Appendix 2

Analysis of Variance (ANOVA) results for fitted models of dependent variables for pumpkin flour-corn grits snack products.

Response		Source	Sum of Squares	df	Mean squares	F-value	P-value
Power Consumption (kw)	Model	Linear	0.3	3	0.100	14.46	<0.0001
		Lack of fit	0.098	11	8.876×10^{-3}	3.49	0.0895
		Pure Error	0.013	5	2.547×10^{-3}		
		Residual	0.11	16	6.898×10^{-3}		
		Total	0.41	19			
Torque (Nm)	Model	Linear	6.96	3	2.32	7.45	0.0024
		Lack of fit	3.27	11	0.30	0.87	0.6078
		Pure Error	1.71	5	0.34		
		Residual	4.98	16	0.31		
		Total	11.94	19			

Response		Source	Sum of Squares	df	Mean squares	F-value	P-value
Pressure Thrust (Bar)	Model	Linear	1965.76	3	655.25	31.72	<0.0001
		Lack of fit	209.60	11	19.05	0.79	0.6565
		Pure Error	120.88	5	24.18		
		Residual	330.48	16	20.65		
		Total	2296.24	19			
Specific Mechanical Energy (SME)	Model	Linear	1.350 × 10-3	3	4.500 × 10-4	6.15	0.0055
		Lack of fit	9.700 × 10-4	11	8.818 × 10-5	2.20	0.1975
		Pure Error	2.00 × 10-4	5	4.00 × 10-5		
		Residual	1.17 × 10-4	16	7.312 × 10-5		
		Total	2.520 × 10-3	19			
Longitudinal Expansion	Model	Linear	51.79	3	17.26	10.35	0.0005
		Lack of fit	21.49	11	1.95	1.87	0.2529
		Pure Error	5.21	5	1.04		
		Residual	6.15	6	1.03		
		Total	1 × 104	20	500.21		

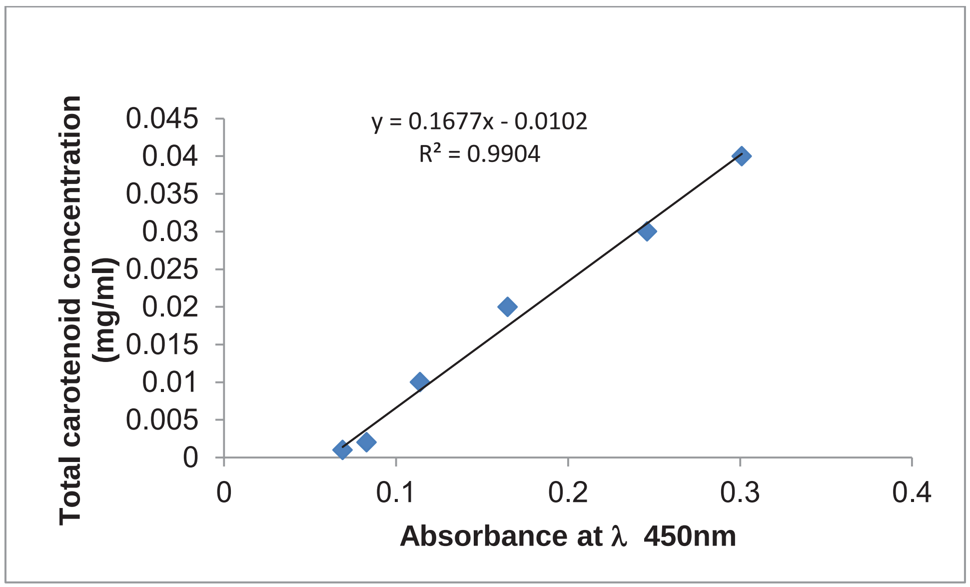
Response		Source	Sum of Squares	df	Mean squares	F-value	P-value
Sectional Expansion	Model	Quadratic	11.25	3	3.75	4.75	0.0261
		Lack of fit	2.61	5	0.52	0.50	0.7706
		Pure Error	5.28	5	1.06		
		Residual	6.28	6	1.05		
		Total	2795.08	20	139.75		
L value	Model	Linear	436.04	3	145.35	5.46	0.0089
		Lack of fit	421.81	11	38.35	50.13	0.0002
		Pure Error	3.82	5	0.76		
		Residual	49.32	6	8.22		
		Total	1.030E+005	20	5151.04		
a value	Model	Quadratic	13.20	3	4.40	18.06	0.0002
		Lack of fit	2.39	5	0.48	46.47	0.0003
		Pure Error	0.051	5	0.010		
		Residual	0.089	6	0.015		
		Total	340.83	20	17.04		

Response		Source	Sum of Squares	df	Mean squares	F-value	P-value
b value	Model	Linear	65.93	3	21.98	13.40	0.0001
		Lack of fit	23.18	11	2.11	3.43	0.0920
		Pure Error	3.07	5	0.61		
		Residual	3.51	6	0.59		
		Total	28995.74	20	1449.79		
Bulk density	Model	Quadratic	144422.89	3	4807.63	45.57	<0.0001
		Lack of fit	1031.10	5	206.22	43.35	0.0004
		Pure Error	23.78	5	4.76		
		Residual	179.20	6	29.87		
		Total	3.038E+005	20	15188.69		
True density	Model	Quadratic	26107.22	3	8702.41	25.29	<0.0001
		Lack of fit	3037.12	5	607.42	7.52	0.0225
		Pure Error	404.01	5	80.80		
		Residual	420.18	6	70.03		
		Total	7.142E+005	20	35712.09		

Response		Source	Sum of Squares	df	Mean squares	F-value	P-value
Hardness	Model	Quadratic	3.675E+005	3	1.225E+005	28.30	<0.0001
		Lack of fit	41514.77	5	8302.95	23.57	0.0017
		Pure Error	1761.56	5	352.31		
		Residual	6879.72	6	1146.62		
		Total	2.810E+006	20	1.405E+005		
Total carotenoid content	Model	Linear	23.94	3	7.98	25.94	<0.0001
		Lack of fit	3.95	11	0.36	1.86	0.2556
		Pure Error	0.97	5	0.19		
		Residual	4.92	16	0.31		
		Total	28.86	19			

Appendix 3

Standard curve of total carotenoid



Appendix 4

Proximate composition of pumpkin flour-corn grits extruded snack

Sample	Barrel Temperature (°C)	Mass Flow (Kg/hr)	Moisture	Ash	Fat	Protein	Carbohydrate
Control (100% Corn grits), BT 150, MF 11.3	150	11.3	8.46	0.39	0.9	28	62.26
5% PF,BT 130, MF 12	130	12	7.81	0.68	2.7	30	58.80
5%PF,BT 170, MF 12	170	12	7.34	0.65	2.7	28.4	60.91
15%PF,BT 150, MF 10	150	10	7.71	1.09	2.7	29.2	59.30
15%PF, BT 150, MF 12.5	150	12.5	7.56	1.65	2.7	28.8	59.29

Appendix 5

PUMPKIN-CORN GRITS EXTRUDED SNACKS PRODUCT

Consumer Sensory Evaluation

Please circle/complete the questions below:

Sex : Male / Female

Age :

All information provided will be used for academic purpose only.

Instructions:

You will be given five (5) different pumpkin-corn grits snack foods.

- **Please rinse your mouth before starting**
- **Evaluate the product in front of you by looking at it and tasting it (Please evaluate one at a time)**
- **Please tick the box to indicate how much you liked and disliked this product**
- **Finally, rank the samples from most liked to least liked**

~Thank you for your time and help~

Cheers

Norfezah Md Nor

Product Code: ___________

(i) Please indicate by placing a mark in the box your **overall acceptability** of this product?

□ □ □ □ □ □ □ □ □

Least Acceptable	Neutral	Highly Acceptable

(ii) Please indicate by placing a mark in the box how you **like** the **colour** of this product?

□ □ □ □ □ □ □ □ □

Dislike extremely	Neutral	Like extremely

(iii) Please indicate by placing a mark in the box how you **like** the **smell** of this product?

□ □ □ □ □ □ □ □ □

Dislike extremely	Neutral	Like extremely

(iv) Please indicate by placing a mark in the box how you **like** the **product's texture** in your mouth?

□ □ □ □ □ □ □ □ □

Dislike extremely	Neutral	Like extremely

(v) Please indicate by placing a mark in the box how you **like** the **taste** of this product?

□ □ □ □ □ □ □ □ □

Dislike extremely	Neutral	Like extremely

(vi) Please indicate by placing a mark in the box your **evaluation** on the **pumpkin flavour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Too Low Just Right Too Strong

(vii) Please indicate by placing a mark in the box if you would **buy** this product as a snack food?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Not Likely Neutral Very Likely

Overall comment(s) of this product as a snack :

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Product Code: ___________

(i) Please indicate by placing a mark in the box your **overall acceptability** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Least Acceptable — Neutral — Highly Acceptable

(ii) Please indicate by placing a mark in the box how you **like** the **colour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(iii) Please indicate by placing a mark in the box how you **like** the **smell** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(iv) Please indicate by placing a mark in the box how you **like** the **product's texture** in your mouth?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(v) Please indicate by placing a mark in the box how you **like** the **taste** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(i) Please indicate by placing a mark in the box your **evaluation** on the **pumpkin flavour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Too Low Just Right Too Strong

(ii) Please indicate by placing a mark in the box if you would **buy** this product as a snack food?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Not Likely Neutral Very Likely

Overall comment(s) of this product as a snack :

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Product Code: ___________

(i) Please indicate by placing a mark in the box your **overall acceptability** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Least Acceptable	Neutral	Highly Acceptable

(ii) Please indicate by placing a mark in the box how you **like** the **colour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(iii) Please indicate by placing a mark in the box how you **like** the **smell** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(iv) Please indicate by placing a mark in the box how you **like** the **product's texture** in your mouth?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(v) Please indicate by placing a mark in the box how you **like** the **taste** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(i) Please indicate by placing a mark in the box your **evaluation** on the **pumpkin flavour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Too Low　　　　Just Right　　　　Too Strong

(ii) Please indicate by placing a mark in the box if you would **buy** this product as a snack food?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Not Likely　　　　Neutral　　　　Very Likely

Overall comment(s) of this product as a snack :

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Product Code: ___________

(i) Please indicate by placing a mark in the box your **overall acceptability** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Least Acceptable — Neutral — Highly Acceptable

(ii) Please indicate by placing a mark in the box how you **like** the **colour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(iii) Please indicate by placing a mark in the box how you **like** the **smell** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(iv) Please indicate by placing a mark in the box how you **like** the **product's texture** in your mouth?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(v) Please indicate by placing a mark in the box how you **like** the **taste** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely — Neutral — Like extremely

(i) Please indicate by placing a mark in the box your **evaluation** on the **pumpkin flavour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Too Low Just Right Too Strong

(ii) Please indicate by placing a mark in the box if you would **buy** this product as a snack food?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Not Likely Neutral Very Likely

Overall comment(s) of this product as a snack :

____

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____

Product Code: ___________

(i) Please indicate by placing a mark in the box your **overall acceptability** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Least Acceptable	Neutral	Highly Acceptable

(ii) Please indicate by placing a mark in the box how you **like** the **colour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(iii) Please indicate by placing a mark in the box how you **like** the **smell** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(iv) Please indicate by placing a mark in the box how you **like** the **product's texture** in your mouth?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(v) Please indicate by placing a mark in the box how you **like** the **taste** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike extremely	Neutral	Like extremely

(i) Please indicate by placing a mark in the box your **evaluation** on the **pumpkin flavour** of this product?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Too Low Just Right Too Strong

(ii) Please indicate by placing a mark in the box if you would **buy** this product as a snack food?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Not Likely Neutral Very Likely

Overall comment(s) of this product as a snack :

____

____

____

____

Rank the samples from most liked to least liked, using the following numbers :

1 = most liked and 5 = the least liked

Sample	**Rank (1 to 5)**
	(Ties are not allowed)
289	________
979	________
175	________
237	________
318	________

~Thank you for your participation~