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High protein bars based on whey proteins

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Preface

This work was carried out at the Faculty of Chemistry, Biotechnology and Food Science in cooperation with Animal and Aquaculture Sciences at the Norwegian University of Life Sciences (NMBU), Aas, Norway.

I would first like to express deep thanks to my adviser Professor Gerd Elisabeth Vegarud who trusted me and my co-supervisor Tove Gulbrandsen Devold who was always kind and helpful and my supportive co supervisor Olav Fjeld Kraugerud, for all the time and energy, they have patiently invested in helping me reach this point, for all the debates and discussions that have molded my thinking, for allowing me to pursue my own ideas, for giving me the pushes I needed to finish, and for helping and supporting me in so many ways.

I would also like to thank the members of the Food Processing Center, especially of Ismet Nikqi and Dejan Miladinovic and Dejan Knezevic for providing me with extruded samples and for teaching me everything there is to know about running efficiently and Irene Comi heaping me with freeze dryer.

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Finally, I want to thank my parents, for their inspiration and support. It has been a long road, but it was worth it.

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Fahimeh Rajabi

Abstract

The composition of a nutrient bar is based on the selection of the ingredients; proteins, carbohydrates, fats and natural sweeteners. In this study, a high protein bar with more than 30 % protein was produced and compared with existing low protein bars (20%) on the market. Such protein-rich bars are favored among health food enthusiasts and athletes.

This experiment was performed in two parts, in the first part (pre-experiment) a literature study of different types of bars on the market was done. Based on these results various ingredients were selected to produce five different high protein bars (approximately 30%) which was made by baking.

The major protein source was whey protein concentrate (WPC80) and cottage cheese, the carbohydrates (including starch) were from oat, sweet potato and quinoa the fat source was various vegetable oils including coconut oil and sesame oil and nuts. For the main experiment, two formulations were selected for producing the bars and two process technologies were applied; extrusion and baking. The formulation and methods for producing a high protein bar are critical for providing function, pleasant taste, texture, and product stability throughout the shelf-life. The main experiment comprised of two types of ingredients that varied mostly in starch composition, oat flakes (3.5%) and sweet potatoes (12.5%) both with quinoa. The formulation with oat flakes and quinoa was extruded, whereas the sweet potatoes and quinoa were baked in an oven. For extrusion, a twin-screw extruder was applied with processing conditions including low shear, high shear, and different moisture contents. The ingredients comprised of whey protein concentrate (37 %), cottage cheese (13.0 %,), roasted quinoa (7.0 %), oatmeal (10.0 %), coconut oil (3.0 %), sesame oil (0.5 %), sesame seed (0.5 %), sunflower seed (2.0 %), peanuts roasted (2.0 %), dried fruits (9.2 %), raisins (1.6 %), glycerin (7.0 %), stevia (4.0 %), honey (3.0 %), baking powder (0.1 %), flavors cinnamon-peanut (0.1 %) .

The extruded bars were analyzed for water content and water activity, hardness, expansion and density. These analyzes were performed immediately after extrusion and after drying and the results after extrusion showed that the expansion of the bars was lowest at low shear- low moisture conditions, however, at high shear- high moisture the best products were obtained (better expansion and less hardiness).

Baking was done in an oven at two temperatures; 50 °C and 100 °C and two cooking times; 10 min and 5 min. The ingredients comprised of whey protein concentrate (29.6 %,), cottage cheese (22.9 %), roasted quinoa (9.4 %), sweet potato (5.9 %), coconut oil (4.0 %), sesame oil (0.7 %), sesame seed (0.7 %), pumpkin seed (2.7 %), almonds (2.7 %), dried fruits (2.8 %), raisin (2.2 %), glycerin (9.4 %), stevia (2.7 %), honey (4.0 %), salt (0.13 %), baking powder (0.13 %), flavors-cinnamon-coconut (0.13 %).

A sensory analysis was made of extruded and baked protein bars, and these were compared with two commercial high protein bars. The results showed that the extruded bars (37 % protein content) did not have the desired taste and texture, although physical analysis of texture, expansion and cohesiveness showed acceptable results. Unlike extruded protein bars, the texture and taste of baked protein bars (29% protein content) was evaluated as better as compared with the two commercial products. This shows that the recipe must be changed if extrusion be used as a manufacturing method so that the product can satisfy consumer requirements.

Sammendrag

Sammensetningen av ernæringsbars er basert på valg av ingrediensene; proteiner, karbohydrater, fett og naturlige søtningsmidler. I denne studien ble det produsert høy-proteinbars med mer enn 30 % protein. Disse ble sammenlignet med eksisterende lav-proteinbars (20 % protein) på markedet. Slike proteinbars benyttes av helsekost entusiaster og idrettsutøvere.

Dette forsøket ble utført i to deler. I første del (for-forsøket) ble det gjort en litteraturstudie av ulike typer bars på markedet. Med disse som utgangspunkt ble det valgt ut ulike ingredienser som ble benyttet til fem ulike bars med høyt proteininnhold (ca. 30 %) som ble laget ved steking. Som hovedproteinkilde ble myseproteinkonsentrat (WPC80) og cottage cheese benyttet, karbohydrater (inkludert stivelse) var fra havre, søt potet og quinoa, fettkilden var ulike vegetabilsk oljer, blant annet kokosolje og sesamolje og nøtter.

Til hoved-forsøket ble to av oppskriftene fra for-forsøket valgt til å produsere bars med to ulike prosesser; ekstrudering og baking. Både sammensetning av ingredienser og selve metoden for å produsere høy proteinbars er kritiske for funksjon, behagelig smak, tekstur og lagringsstabilitet av ferdig produkt. Oppskriftene som ble benyttet i hoved-forsøket besto av ulike ingredienser med stivelse fra ulike kilder; havregryn (3,5 %) og søtpoteter (12,5 %) begge med quinoa. Oppskriften med havregryn og quinoa ble ekstrudert, mens oppskriften med søtpotet og quinoa ble bakt i ovn.

Til ekstrudering ble en «tvilling-skrue» ekstruder benyttet, og effekt av ulike prosessbetingelser ble undersøkt; lav og høy skjærkraft og forskjellig vanninnhold. Ingrediensene bestod av myseproteinkonsentrat (37 %), cottage cheese (13,0 %), quinoa (7,0 %), havregryn (10,0 %), kokosnøttolje (3,0 %), sesamolje (0,5 %), sesam frø (0,5 %), solsikkefrø (2,0 %), peanøtter (2,0 %), tørket frukt (9,2 %), rosiner (1,6 %), glyserol (7,0 %), stevia (4,0 %), honning (3,0 %) , bakepulver (0,1 %), smak kanel-peanøtt (0,1 %). De ekstruderte bars ble analysert for vanninnhold og vannaktivitet , hardhet, ekspansjon og tetthet. Disse analysene ble utført umiddelbart etter ekstrudering og etter tørking, og resultatene viste at bars produsert ved kombinasjon av lav skjærkraft og lav mengde tilsatt vann var hardest, men kombinasjonen høy skjærkraft og høy vanntilsetning gav de beste produktene i form av bedre ekspansjon og mindre hardhet.

Baking ble gjort i en ovn ved to forskjellige temperaturer; 50 °C og 100 °C og to tider; x min og y min. Ingredienser bestod av myseprotein konsentrat (29,6 %), cottage cheese (22,9 %), quinoa (9,4 %), søtpotet (5,9 %), kokosolje (4,0 %), sesamolje (0,7 %), sesamfrø (0,7 %), gresskarfrø (2,7 %), mandler (2,7 %), tørket frukt (2,8 %), rosiner (2,2 %), glyserol (9,4%), stevia (2,7%), honning (4,0 %), salt (0,13%), bakepulver (0,13%), smak kanel-kokosnøtt (0,13%).

En sensorisk analyse ble gjort av ekstruderte og bakt proteinbars og disse ble sammenlignet med to kommersielle høy-proteinbars. Resultatene viste at de ekstruderte bars (37 % proteininnhold) ikke hadde ønsket smak og tekstur, selv om fysiske analyser av tekstur, ekspansjon og «kohesiveness» viste akseptable resultater. I motsetning til ekstruderte proteinbars, var tekstur og smak av bakte protein bars (29 % proteininnhold) vurdert som bedre sammenlignet med de to kommersielle produktene. Dette viser at oppskriften må endres dersom ekstrudering skal benyttes som fremstillingsmetode slik at produktet kan tilfredsstille forbrukerens krav.

Objective:

The objectives of this study were as followed,

- To perform a literature study of existing commercial protein bars and their composition
- To produce a high protein bar consisting of > 30% protein by selecting the proper mix of ingredients and with the following
    - acceptable texture, flavor, smell and taste
    - moderate moisture content and low water activity for long time storage
    - use of glycerol to keep water activity low and create desired water content and crunchiness
- To use two type of technologies; the extrusion and baking technology were used to study the effect of the different type of methods to increase utilization of proteins and improve the nutritional value.

Abbreviation

RMP = Revolutions per minute (abbreviated rpm, RPM, rev/min, r/min) is a measure of the frequency of rotation

W_A =water activity

GI = The glycemic index or glycemic index

IMF =Intermediate moisture foods

HPB= high protein bar

T_g = phase transition temperature

SME = specific mechanical energy

RDA=the recommended dietary allowance

Contents

1 Introduction

1.1. General Background

The increasing awareness of healthy foods has led to a continuous search for and development of products which can offer convenience, desirable sensory attributes and all necessary nutrients as specified in the recommended daily allowances [1]. The first bars were introduced in the early 1980s, they were exclusively consumed by fitness enthusiasts and athletes regardless of taste and texture. The nutritional bar is a category of bar-shaped products comprised of proteins, carbohydrates, fats and in addition vitamins and minerals[2]. The nutritional bars can be classified into different categories (see section 1.3) or may fit into more than one. Moreover, there is a wide range of serving size for the nutritional bars on the market [3, 4]. It has been estimated an increasing trend in the global market using proteins in formulated foods (bars and beverages) and dietary supplement up to 5.5 million metric tons by 2018, Figure 1 [5]. In addition, the high protein bar market including sports nutrition, muscle building healthy supplement and weight loss management products, is expected to increase to about $3 billion in 2016 in the U.S.[6]. Due to the growing trend among consumers for healthy, natural and convenience foods, it is crucial to developed snack foods with high nutritional value (protein, vitamins, minerals, fiber) and different technologies that provide the required functionality [7]. Taste and texture are key points to the general consumers who are concerned about their health and wellness. On the other side, the function of foods which target several health objectives are important to professional athletes and fitness followers.

Most of the commercial high protein bars (HPB) belong to the intermediate-moisture food (IMF) category with a water activity (A_w) in the range of 0.50–0.85 [8]. High-protein bars (protein bars) consist of high-quality protein, sugars and other ingredients and have a minimum of water (water activity 0.6-0.85). It is important to keep water activity low to ensure a long shelf life and avoid chemical, physical and biological reactions which may result in adverse effects on product quality such as changes in flavors, colors and texture, making the product less attractive to the consumers [9].

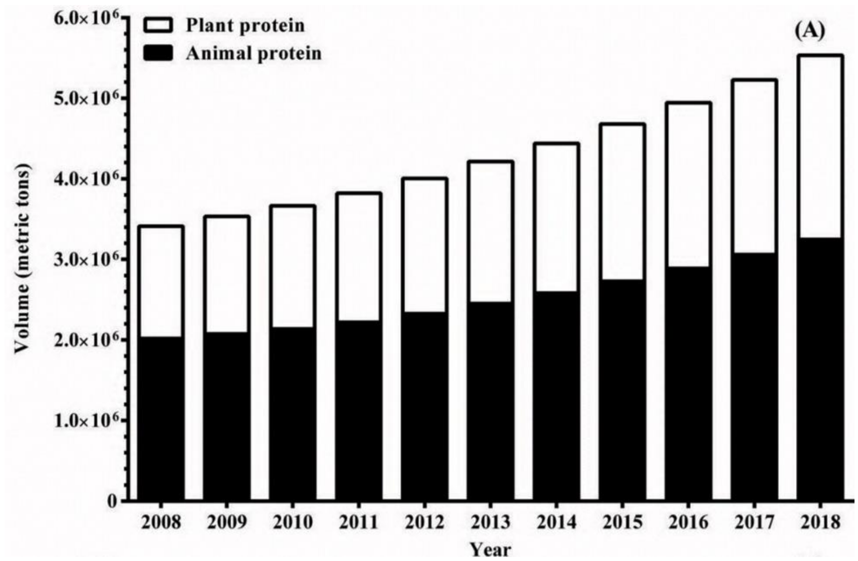


Figure 1. Total market volume of (A) global food protein ingredients[5]

The snack food category is not fully described and therefor the difference between snacks and meals is often unclear. The term "snacking" has been defined as "an intake of food over a fifteen-minute period and excluding food defined as a snack but eaten as a meal" [10]. Others have described snacks compared to meals as "snacks are smaller than a regular meal and less structured eating episodes" [11]. On the other hand, snacking has been considered as the consumption of food between the ordinary three meals a day[12]. Specific types of foods, especially those considered as unhealthy because of low nutritional value (e.g. poor in micronutrient; high content of fat and/or added sugars; or low in fiber, like cookies and potato chips) are also considered as snacks[13].

1.2.Types of bars

Many different types of bars are available in the market, including meal replacement bars or bars aimed at the nutritional requirements for diabetics, children, athletes and women [14]. The market is divided into four categories: 1) granola bars, 2) nutritional/intrinsic health value bars (referred to as nutritional bar below), 3) breakfast/cereal/snack bars and 4) rice snack squares. For all these groups the marketing activities have focused on two factors: health and convenience[15]. The nutritional bar may be defined as a type of snacking paired with the health benefits whereas according to other sources nutritional bars are classified base on the portability and convenience of snack category[2]., The nutrition bar category, as mentioned above, is further divided into four groups including high protein bars, energy bars, healthy snacks and weight management/diet plans. The high protein bar segment is the largest and comprises 34 % of the total nutritional bar market (

Figure 2)[3].According to some sources. there is difference between high protein nutritional bars (HPNB) and protein bars, which it has considered that the high protein bar (15-20 g protein/serving) contain a higher protein concentration, up to 5 grams in serving size, compared with protein bar (5-15 g protein/serving) The target group for the high protein nutritional bar are mostly bodybuilders people to use it this kind of bar as a supplement[4].

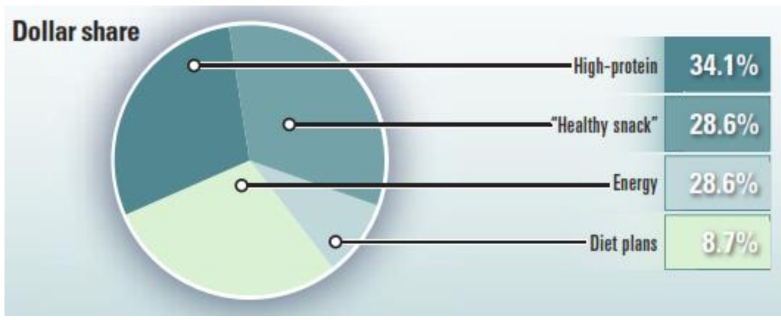


Figure 2. Market Share by Nutrition-Bar Type -Sources: The Nielsen Co., U.S. Nutrition [3]

Recently, nutritional and health bars have seen strong growth in the market due to wellness/healthy image, and the sports enthusiast are not solely customers any more. Briefly, the classification of snack, cereal and nutrition bars can be subjective, and producers can sell brands for different consumptions purposes. Nutrition bars can be used for multiple occasions, for this reason many nutritional bars may go with more than one of the classifications[16].

1.3.Formulation

The product developer faces many challenges when producing nutritional bars; ingredients must meet specific nutritional requirements and the final product should meet consumers need for convenience and health benefits. For this reason, formulators must choose the right mix of ingredients to create products with desirable sensory attributes and nutritional value associated with health criteria for the specific type of bar. Although numerous formulations/receipts have been made until now, for some of the bars on the market acceptable taste is not yet achieved. Such products will not be successful as one of the best ways to increase repeated and successfully buying is a good taste, otherwise and product will die on the shelf regardless how healthy it might be [17].In processing new products, it is crucial to optimize both sensory properties (appearance, color, flavor, texture), and functional properties of the various components (to provide the perfect balance) for proper acceptability and exceptional quality [18]. Therefore, the improvement of new products is a key factor for the survival of many businesses and is closely dependent upon the demands and consumer preferences[19].As different kinds of ingredients are being used in formulation nutrition bars, some critical issues such as taste, texture, potency and ingredient interaction are addressed early in the product development. Moreover, it is not a problem how many nutrients are used in a bar, it all comes down to the taste[17].

1.4. Nutritional bar's function

The function of nutritional bars dependents on all the ingredients and the formulation. For instance, the bars are used in sport and fitness contain a high-quantity of proteins (20% to 35%) to improve muscle regeneration and rebuild damaged tissue after physical activity. Energy bars with high content of carbohydrates provide the body with a long and steady stream of energy.

1.5 Health aspects

Protein

Proteins are made up of 20 different amino acids; the essential and nonessential (Table 1)., The non-essential amino acids can be synthesized in the body, but essential amino acids must be provided with the food. In the human body, proteins fulfill many important functions including buildup of cells and tissue repair, formation of hormones and enzymes, fluid balance and providing energy. Almost 60% of the protein mass is located in the skeletal muscles [21, 22]. Although, there is potential for adverse effects in long-term in using protein over the recommendation.

Table 1. The 20 amino acids, divided into essential and non-essential. Compound in bracket show the source from which the non-essential amino acids are synthesized.[20]

Essential	Non-essential	
Isoleucine	Alanine (from pyruvic acid)	Glycine (from serine and threonine)
Histidine	Arginine (from glutamic acid)	Proline (from glutamic acid)
Leucine	Asparagine (from aspartic acid)	Serine (from glucose)
Methionine	Aspartic Acid (from oxaloacetic acid)	
Lysine	Cysteine	
Phenylalanine	Glutamic Acid (from oxoglutaric acid)	
Tryptophan	Glutamine (from glutamic acid)	
Valine		

Protein recommendations

In general, the recommended dietary allowance (RDA) for protein intake for general health for individual adult men and women is 0.8 grams per kilogram of body weight per day [21]. So, protein consumption for a person of 75 kg (165 pounds) can be an average of 60 grams per day. Since proteins approximately contain 4 kilocalories per gram, 60 grams of protein provides 240 kilocalories. On the other hand, it is recommended that protein provides 10-35 percent of the daily energy intake [22]. For instance, if you daily need to consume 2,000 Kilocalories per day, around 200 to 700 kilocalories should come from protein per day[23].

Physical activity and the body's need for protein

The protein requirements increase during physical activity [21] depending on energy expenditure, duration of exercise and frequency, the type of exercise and the health situation, body size, age and gender. Values of Dietary Reference Intakes (DRIs) recommendations for persons who exercises on regular basis are listed below and in Table 2 [24-26]. The recommended protein requirement for athletes who participate in endurance sports should be 1.2-1.4 g/kg body weight/day and 1.6-1.8 g/kg body weight/day for individuals involved in resistance or instant exercise[27].The acceptable macronutrient distribution range (AMDR) suggests 10-35% of calories from protein.

Table 2. Dietary Reference Intakes (DRIs) for macronutrients for active individuals [27]

Nutrient	New Guidelines – 2002[1]	Old Guidelines – 1989[2]	Guidelines for Active Individuals[3]
Carbohydrate	45-65% of total energy	≥ 50% of total energy	The amount of carbohydrate required for moderate intensity exercise is 5-7 g/kg body weight; 7-12 g/kg body weight for high intensity endurance activities.
Protein	10-35% of total energy; 0.8 g/kg of body weight	10-15% of total energy; 0.8 g/kg of body weight	Protein requirements are typically higher in active individuals. Recommendations range from 1.2-1.7 g of protein/kg body weight. This level of protein typically represents 15% of total energy.
Fat	20-35% of total energy	≤ 30% of total energy	Fat intakes between 20-35%. Carbohydrate and protein needs should be met first.

Established adverse effects of excessive protein intake

There are many adverse health effects associated with consuming in excess of recommended amounts protein[28]. This has been observed in particular for physically active males who goes to college and regularly are consuming excessive protein[23]. Several studies have reported that high protein intake (those over 2 g/kg/d) interfere with health and may stress renal function[21, 28].

Carbohydrates

Carbohydrates, also referred to as sugars or saccharides, are the most common source of energy for humans. There are different types of saccharides, monosaccharides, disaccharides and polysaccharides. The most common examples of carbohydrates in the human diet are the following[29]:

- Monosaccharides: Glucose, galactose, ribose, ribulose, fructose.
- Disaccharides: Maltose, lactose, sucrose
- Polysaccharides: Starch, cellulose (dietary fiber), pectin, inulin

Based on their function polysaccharides are divided into two types: storage polysaccharides (starch) and structural polysaccharide (cellulose). Starch is a storage form of energy in plants and it made up two glucose polymers which are amylose (linear) and amylopectin (branched) Figure 3 .

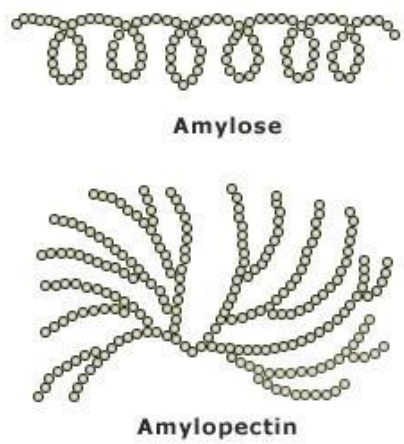


Figure 3. Amylose (linear) and amylopectin (branched)[29]

Foods are grouped based on the amylose content in the starch. Table 3. The relative proportion of amylose to amylopectin determines the physical-chemical properties of starch and the nutritional aspects. All starches comprise different ratios of amylose and amylopectin. This proportion differs among the various types of starch and within the same family of plants. Waxy starches contain an exceptionally high amount of amylopectin, they have no more than 10% amylose.

Table 3. The different amylose families [30]

The different amylose families			
Cereals (15 - 28% amylose)	**Tubers** (f 17% - 22% amylose)	**Pulses (**33 - 66% amylose)	**Fruit** (5-10% amylose)
Tender wheat Coarse wheat Rice Corn Oats Barley Rye Sorghum Millet	Potatoes Sweet Potato Cassava Tropical yam -US/ yam -UK Taro Malanga, Tania	String beans Peas Chick peas Lentils Beans	Bananas Mangoes Apples

The structure of starch is changed in the presence of water and heat. The water penetrates the starch granules and heat will affect the granules to swell from the center. This is called gelatinization. The degree of gelatinization is depending on the amount of amylose. Higher degree of gelatinization occurs if the amount of amylose is lower. Based on the plant, starch generally comprises of 20 to 25 % of amylose and 75% - 80 % amylopectin. Generally, grain-derived starches contain a higher amylose level than the tuber-derived starches Table 4 .

Table 4. Ratio of amylose and amylopectin in some starches[31]

source	amylose (%)	amylopectin (%)
potato	21	79
maize	28	72
wheat	26	74
tapioca	17	83
waxy maize*	-	100

In addition, it has been reported that starches with a lower content of amylose will show higher Glycemic Index (GI). Inversely, starches with a higher amount of amylose will gelatinize at higher temperatures and during digestion will be hydrolyzed to glucose more slowly (low Glycemic Index). For instance, potatoes with an extremely low amylose content has a high glycemic index, while lentils with a high in amylose show a very low GI [30].

The glycemic index is a classification of carbohydrate-containing foods according to the blood glucose response they elicit [35]. "High GI" foods increase blood glucose more rapidly than "medium GI" or "low GI" food. Generally, carbohydrates that have a fast and high impact on blood glucose are digested and absorbed rapidly after they are eaten, resulting in the highest GI and the sharpest increase in blood glucose [36]. Glycemic index values are categorized into three groups [37]:

- High GI 70 or higher
- Intermediate GI 56-69
- Low GI 0-55

Prior to exercise, the consumption of low glycemic index (LGI) foods raise blood sugar gradually and provide a sufficient supply of energy that can be used during exercise. Slowly digested carbohydrates such as starch present in pasta or legumes have a low GI. High GI foods are recommended after endurance exercise or for persons with low blood sugar condition [37].

1.6.Bar ingredients

Typically, the food bars comprise of proteins and carbohydrates in addition, other ingredients for instance, glycerol is commonly added to the high protein bar formulations as a humectant to provide softness. Moreover, oil, nuts sugars, starches, dietary fibers and flavors, and mixtures thereof are part of food bar composition. In addition, minerals and vitamins are generally added [38]. Typically, the ingredients applied During the extrusion process interactions among the ingredients are formed and these have impact on the properties of the final product.

Generally, a high protein bar will provide an energy of approximately 150-300 kcal per 100 g [32]:

• 25 – 40 g protein

• 10 – 30 g carbohydrate

• 0 – 5-g g fat

1.6.1. Protein-sources

A variety of protein sources may be applied, while plants proteins are typically used, other sources like dairy proteins including milk protein , casein and whey protein and mixtures thereof may be selected[33]. The percentage of protein involved in the ingredient(s) utilized may vary from range 1% to about 90% by weight [33]. For instance, suitable plants include legumes, oilseeds, cereal grains, tubers, pseudo grains. Legumes such as beans, lentils and peas. Typically, seeds are high in protein, such as pumpkin seeds, peanuts, pistachios, almonds, sunflower seeds, sesame seeds, and flax seed[34]. Adequate examples of a variety of sources of protein-containing material in protein bars are listed in Table 5[33].

Table 5. Examples of a variety of sources of protein-containing material[33]

Protein combinations					
First protein source	**Second ingredient**				
Whey protein	Wheat	Wheat and oat	Corn and rye	Buckwheat	Wheat and potato
Whey protein	Dairy	Wheat and millet	Corn and triticale	Pea	Wheat and tapioca
Whey protein	Egg	Wheat and rye	Corn and buckwheat	Peanut	Wheat and arrowroot
Whey protein	Corn	Wheat and triticale	Corn and pea	Lentil	Wheat and amaranth
Whey protein	Rice	Wheat and buckwheat	Corn and peanut	Lupine	Corn and wheat
Whey protein	Sorghum	Wheat and pea	Corn and lentil	Channa (garbonzo)	Corn and dairy
Whey protein	Oat	Wheat and peanut	Corn and lupine	Rapeseed (canola)	Corn and egg
Whey protein	Millet	Wheat and lentil	Corn and channa (garbonzo)	Cassava	Corn and rice
Whey protein	Soybeans	Wheat and lupine	Corn and rapeseed (canola)	Sunflower	Corn and barley
Whey protein	Rye	Wheat and channa (garbonzo)	Wheat and cassava	Potato	Corn and sorghum
Whey protein	Triticale	Wheat and rapeseed (canola)	Corn and sunflower	Tapioca	Corn and amaranth
Whey protein	Corn and arrowroot	Wheat and cassava	Corn and potato	Arrowroot	Corn and triticale
Whey protein	Corn and amaranth	Wheat and sunflower	Corn and tapioca	Amaranth	Corn and buckwheat
Whey protein	Corn and rye	Wheat and sorghum			

Whey protein

Whey proteins are one group of proteins (20%) present in milk, whereas the main protein group is the caseins (80%). Whey is the liquid material when casein is coagulated with rennet during cheese making. In cheese production, 10 kilograms of milk produces 1 kg of cheese and 9 kg of whey. You may find the production of different whey ingredients is outlined in Figure 4.

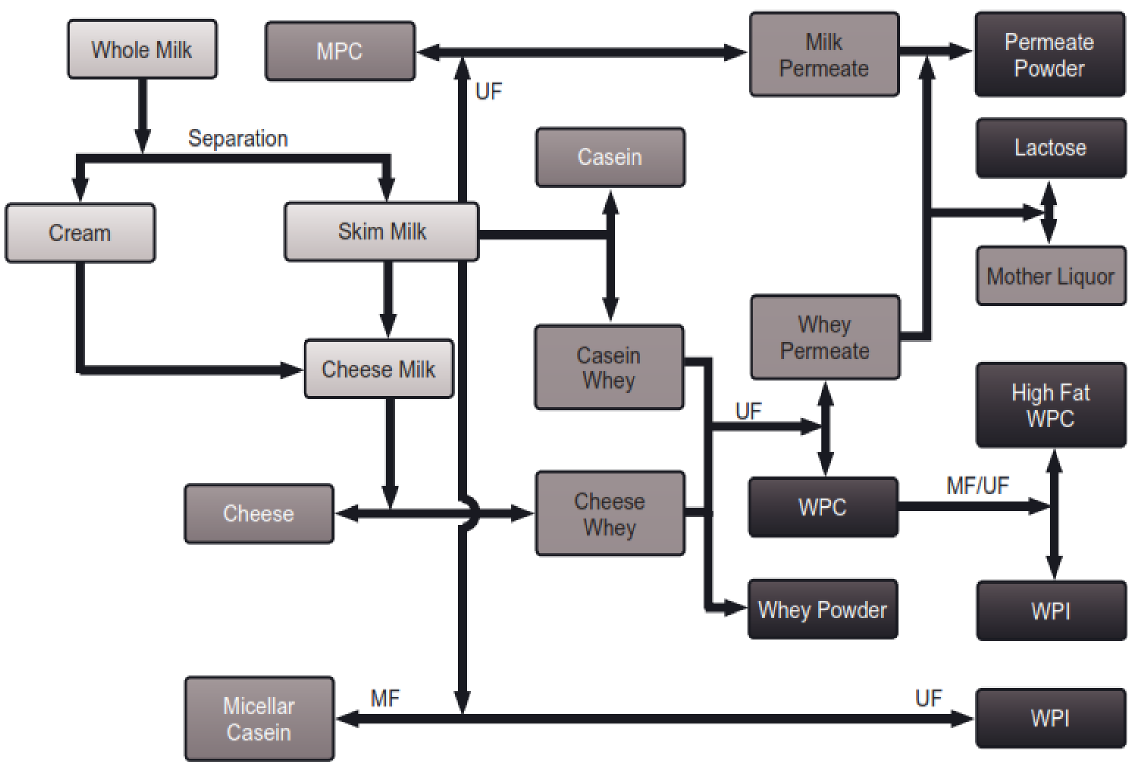


Figure 4. Flow diagram for the production of whey ingredients[35]

Liquid whey contains proximately 6% solids **comprising** lactose, minerals, minor amounts of fat and 0.7 % protein. The whey protein fractions comprise of beta-lactoglobulin, alpha-lactalbumin, bovine serum albumin (BSA), immunoglobulins and several other minor proteins. Additionally, it may contain glycomacropeptide (GMP) if the whey is produced from renneted cheese [35].

Whey streams processing includes two objectives, reduction of the water content and use different isolation and fractionation techniques to obtain the different ingredients. The protein content of whey can be increased by various fractionation techniques including ultrafiltration (UF), Nano filtration (NF) and microfiltration (MF) or by ion exchange. Drying these fractions increase shelf time and reduce the cost of transportation. The protein content in whey products varies from 12,5% in whey powder to whey protein isolates which ranges with minimum 90% [35].

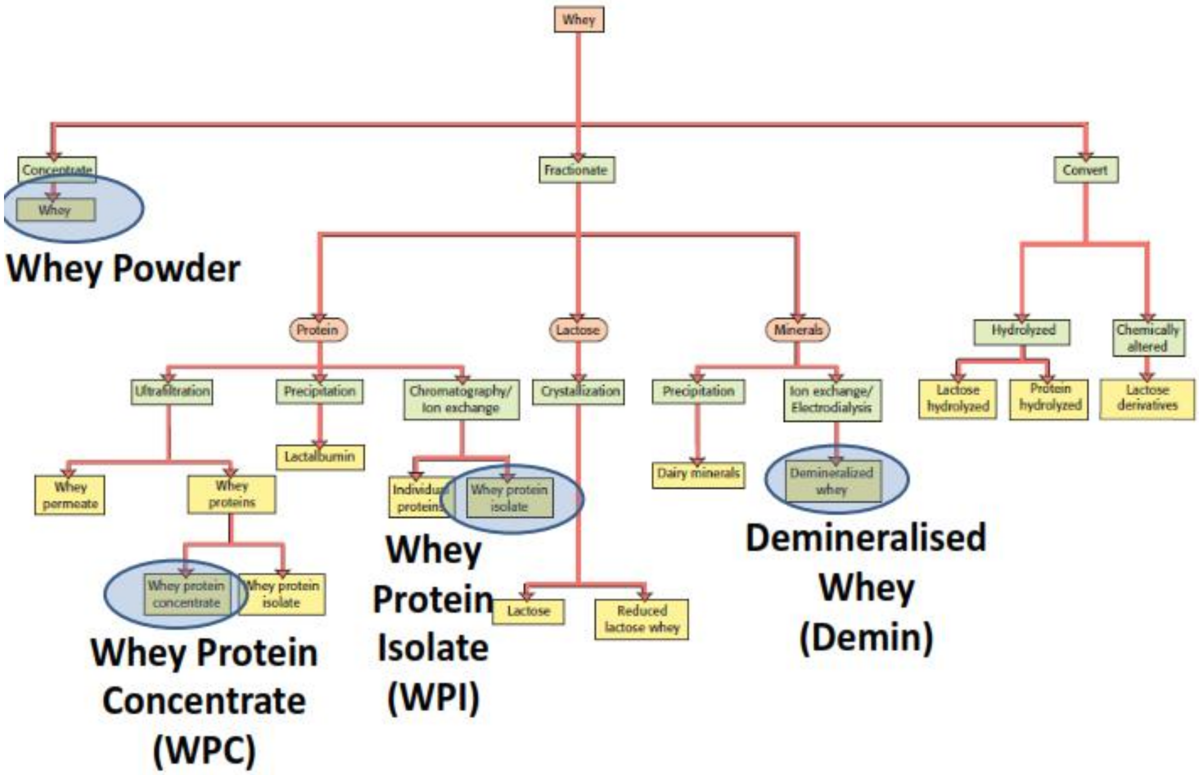


Figure 5. Overview of processing options of whey and different commercially available fractions [36]

Whey protein products typically divide into three groups depending on their protein content, such as whey protein concentrate, whey protein isolate and hydrolyzed Table 6. It is important to consider that the product composition may vary by manufacturer [37] .Whey protein products have several functional and nutritional properties.

Table 6. Whey protein types [40]

Type	Protein	Lactose	Fat	Common application
Whey-protein-concentrate	25-89%	4-52%	1-9%	Protein beverages and bars, confectionery and bakery products, infant formula and other nutritional food products
Whey-protein isolate	90-95%	0.5-1%	0.5-1	Protein supplementation products, protein beverages, protein bars and other nutritional food products

Hydrolyzed-whey protein	80-90%	0.5-10%	0.5-8	Infant formula and sports and medical nutrition products

Nutritive properties and functional properties of whey proteins including water binding, solubility, gelation, emulsification, foaming, flavor binding is widely used in food industry. Recently in many foods including sports nutrition foods, snack foods, dairy, infant formulas, meats, confections, bakery, beverages and other food products, whey protein helps to improve the functionality of foods product.

Whey proteins have a high nutritional quality due to the high content of branched-chain amino acids including leucine, isoleucine, and valine Table 7. Leucine is important for growth and repair of tissue [43]. Leucine, isoleucine, and valine are considered important factors in metabolic regulation of protein and glucose homoeostasis, and lipid metabolism by influencing weight control [38]. Energy obtained from these amino acids can be useful in sports drinks. In addition to be an energy source they assist in muscle building.

Table 7. Preschool age and amino acid requirements set by FAO / WHO (1989)[35]

Essential amino acid	Recommended requirement (mg/g protein)	WPC 80 (mg/g protein)
Isoleucine	28	54
Leucine	66	119
Lysine	58	94
Methionine + Cysteine	25	52
Phenylalanine + Tyrosine	63	68
Threonine	34	66
Tryptophan	11	20
Valine	35	51
Histidine	19	21

Whey proteins are emerging as significant ingredients in the food industry. Their mild taste make them suitable in products with a broad variety of flavors. For instance, consumption of whey proteins in sports and snack products provides the nutrients demonstrated positively result in the body composition[39]. Table 8 shows examples of whey ingredients and their advantages in bar applications.

Table 8. U.S. Whey Ingredients Composition and Advantages in Bar Applications [48]

Whey Ingredient	Protein (%)	Carbohydrate (%)	Fat (%)	Minerals (%)	Advantages
WPI	90-92	0.5-1	0.5-1	2-3	• Highest protein levels • Lowest levels of lactose and fat
WPC 80	80-82	4-8	4-8	3-4	• High levels of protein • Low levels of lactose and fat
WPC with 34 to 79% protein and modified WPC	34-79	Varies	Varies	Varies	• Cost-effective option to add functional and nutritional ingredients • Clean label
Hydrolyzed whey protein (HWP) and blends of HWP, WPC and WPI	80-92	Varies	Varies	Varies	• Improves shelf life and raises the protein level • Clean label • Faster protein absorption and digestibility
Extruded whey proteins (whey crisp)	40-80	Varies	Varies	Varies	• Adds textural variety • Equilibrates moisture over time
Dairy calcium and milk minerals	1-8	1-6	<0.5	76-77.5	• Excellent source of calcium • Balanced mineral blend
Nonfat dry milk	34-37	49-52	0.6-1.25	8.2-8.6	• Clean flavor and label • Excellent nutrition
Lactose	0.1	99-100%	0	0.1-0.3	• Limited sweetness • Synergistic effect on flavor and color development • Lower glycemic index carbohydrate

Whey Protein Concentrate

Whey protein concentrates (WPC) are processed by ultra filtration of whey. The proteins are concentrated while lactose and minerals are decreased. Different protein content can be produced with the utilization of diafiltration Figure 6. Typical composition of whey protein concentrates [35][35]. WPC 80 are applied as protein supplements and are especially suitable for utilization in nutritional drinks, sports, and nutritional bars[40].

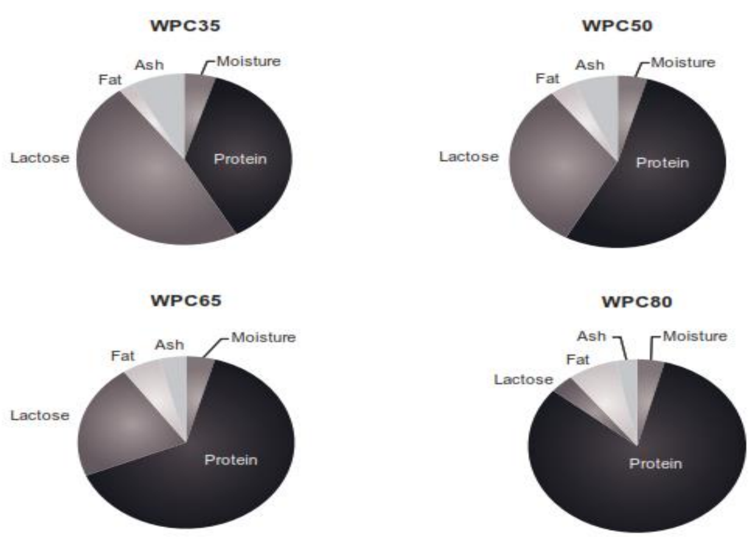


Figure 6. Typical composition of whey protein concentrates [35]

Cottage cheese

Cottage cheese is a fresh cheese. It is produced from cow's milk by acidified and rennet coagulation. The curd is drained but not pressed, the result is an excellent source of rich proteins. Cottage cheese is specifically high in casein due to most of the whey being drained away. Casein contains different types of all the essential amino acids in comparison low in sulfur-containing amino acids [41].Different kinds of cottage cheese are made from milk with various fat contents and in small-curd or large-curd preparations[42]. Cottage cheese is considered as a healthy food, a 100 g portion of cottage cheese (creamed, low fat or dry curd) is the source of vitamin B12, riboflavin and vitamin B6 and some mineral including calcium, phosphorous, zinc, folate[43]. Cottage cheese is favored among some health food enthusiast, bodybuilders, runners, swimmers and weightlifters for its high levels of casein protein (a longer-lasting protein) but the same time low in fat. A lot of bodybuilders take casein protein before get to bed to prevent muscle loss. Compositions for cottage cheese are typically as follows Table 9 [44]:

Table 9. Compositions of different types of cottage cheese

Variety	Moisture	Protein	Fat	Carbohydrate	Ash
Creamed (4% milkfat)	79%	12.5%	4.5%	2.5%	1.5%
Low-fat (2% milkfat)	79%	14%	2%	3.5%	1.5%
Low-fat (1% milkfat)	80%	12.5%	1%	2.5%	1.5%
Dry curd	80%	17%	0.5%	2%	0.5%

Quinoa

Quinoa (Chenopodium quinoa, Willd) is a native pseudo-cereal crop of the Andean region of Latin America[45]

Figure 7. Quinoa is considered as "a complete food" for many reasons. Basically, the protein content is quantitatively and qualitatively high. It contains all the essential amino acids in adequate amounts, which many other crops do not have. From this point of view, it makes quinoa perfect to be used as the protein supplement. In addition, the lipid fraction of in quinoa comprises unsaturated fatty acids in large proportion, which provide more health benefits than saturated fatty acids. [46].

Figure 7. Quinoa (Chenopodium quinoa, Wild) [47]

protein content in dry matter of quinoa is within a range 12-14 g/100g and that the highest average is approximately 14-16.5 g/100g Table 10 [48]. The variation is reasonable as all biological materials vary in composition depending on breed, climate and other factors.

Table 10. Composition of six quinoa ecotypes from the three genetic zones of Chile [48]

	North		Center		South	
	Ancovinto	Cancosa	Cahuil	Faro	Regalona	Villarica
Moisture	7.74 ± 0.07[a]	9.29 ± 0.06[b]	13.17 ± 0.02[c]	13.17 ± 0.10[c]	14.27 ± 0.03[d]	15.18 ± 0.02[e]
Ash	3.36 ± 0.06[a]	3.46 ± 0.10[a,b]	3.15 ± 0.07[c]	3.53 ± 0.04[b,d]	3.61 ± 0.09[d]	3.65 ± 0.09[d]
Protein (N x 6.25)	12.85 ± 0.28[a]	13.59 ± 0.08[b]	11.41 ± 0.54[c]	11.32 ± 0.19[c]	14.66 ± 0.38[d]	16.10 ± 0.14[e]
Fat	6.24 ± 0.06[a]	5.88 ± 0.13[b]	7.15 ± 0.16[c]	6.59 ± 0.10[d]	6.42 ± 0.09[a,d]	5.97 ± 0.07[e]
Crude Fiber	1.45 ± 0.06[a]	1.91 ± 0.28[b]	1.33 ± 0.46[a]	1.50 ± 0.14[a]	1.90 ± 0.23[b]	2.81 ± 0.07[c]
Total carbohydrates	68.36 ± 0.42[a]	65.88 ± 0.08[b]	63.80 ± 0.68[c]	63.89 ± 0.17[c]	59.14 ± 0.27[d]	56.73 ± 0.19[e]

Value are expressed as mean±standard deviation (n=3). All data are expressed as g/100 g d.m. N: Nitrogen
Different letters in the exponential in the same row show there are significant differences (p-value<0.05).

It has been reported that, quinoa has a higher protein content than some of the most common cereal in wet matter with 16.5 g/100g, which is higher than that barley, rice, maize, and wheat Table 11.

Table 11. Chemical composition of quinoa and some cereals and legumes (g/100 g grain) [49]

Cereal	Proteins	Lipids	Fiber	Ash	Carbohydrates
Wheat	14.3	2.3	2.8	2.2	78.4
Rye	13.4	1.8	2.6	2.1	80.1
Barley	10.8	1.9	4.4	2.2	80.7
Millet	14.5	5.1	8.5	2.0	71.6
Oat	11.6	5.2	10.4	2.9	69.8
Amaranth	16.6	7.2	4.1	3.3	59.2
Buckwheat	12.3	2.3	10.1	2.3	66.0
Quinoa	16.5	6.3	3.8	3.8	69.0

Nutritionally, the protein quality in quinoa seeds (cooked and leached) is closer to human requirements than any other common cereal grains, being equivalent to milk in protein quality[50]. This grain is particularly rich in certain essential amino acids, such as, lysine, histidine and methionine. As lysine are not present in an adequate amount in the vegetable kingdom[51], and it provides the perfect complement to legumes, which are often not high in histidine and methionine + cysteine. In addition, quinoa contains a well-balanced protein fraction in view of the recommendations of the FAO Table 12 [51, 52].

Table 12. Essential amino acids in quinoa and other foods (g/100 g protein)[51, 52]

	Quinoa	Maize	Rice	Wheat	Bean	Milk	FAO[a]
Histidine	3.2	2.6	2.1	2.0	3.1	2.7	2.6
Isoleucine	4.9	4.0	4.1	4.2	4.5	10.0	4.6
Leucine	6.6	12.5	8.2	6.8	8.1	6.5	9.3
Lysine	6.0	2.9	3.8	2.6	7.0	7.9	6.6
Methionine[b]	5.3	4.0	3.6	3.7	1.2	2.5	4.2
Phenylalanine[c]	6.9	8.6	10.5	8.2	5.4	1.4	7.2
Threonine	3.7	3.8	3.8	2.8	3.9	4.7	4.3
Tryptophan	0.9	0.7	1.1	1.2	1.1	1.4	1.7
Valline	4.5	5.0	6.1	4.4	5.0	7.0	5.5

[a]as reported by Koziol (1992); [b]methionine + cystine; [c] Phenylalanine + tyrosine; FAO – Food Agriculture Organization

Studies have indicated that the albumins and globulins are the main protein fractions of quinoa and a low amount of prolamins shows that quinoa is gluten-Table 12[52].

Table 13. Subgroups of Protein from Quinoa, Maize, Rice, and Wheat (% Total Protein) (Koziol 1992)[46]

	Albumin + Globulins	Glutenins/ Glutelins	Gliadins/ Prolamins
Quinoa	76.6	12.7	7.2
Maize	38.3	37.2	24.5
Rice	19.2	71.9	8.9
Wheat	17.1	54.4	28.5

Moreover, regarding the content of minerals and vitamins, quinoa is rich in vitamin E, vitamin B complex, and minerals Table 14. Finally, quinoa contains bioactive compounds like phenolic compounds, flavonoids, and carotenoids providing vital health benefits[46].

Table 14. Mineral composition (mg/kg dry wt.) and vitamin concentrations (mg/100 g dry wt.) in Quinoa and some cereals [51, 52]

Minerals	Quinoa	Wheat	Rice	Barley
Ca	1487	503	69	430
Mg	2496	1694	735	1291
K	9267	5783	1183	5028
P	3837	4677	1378	3873
Fe	132	38	7	32
Cu	51	7	2	3
Zn	44	47	6	35
Vitamins				
Thiamin (B_1)	0.38	0.55	0.47	0.49
Riboflavin (B_2)	0.39	0.16	0.10	0.20
Niacin (B_3)	1.06	5.88	5.98	5.44
Ascorbic acid (C)	4.00	0	0	0
α-Tocopherol	5.37	1.15	0.18	0.35
β-Carotene	0.39	0.02	NR	0.01

NR – not reported

1.6.2 Carbohydrate Source

The protein source ingredients are typically mixed with at least one carbohydrate source. Usually, the carbohydrate source is a cereal flour, starch, pre-gelatinized starch or a modified food starch. Legumes rich in starches like fava beans, lentils and peas or wholegrain flours of these ingredients may also be used. Irrespective of source, the amount of starch used affects texture in the extrusion process in relation of expansion of the product. A high proportion of starch will usually yield products with crispy texture and a low proportion of starch usually results in products being chewy, dense, and hard. Intrinsically, the percentage of starch available in the extruded protein composition can be different based on the required texture of the product (more amount of starch, result in crunchy texture). The percentage of starch in the ingredients may vary from about 1% to about 90% by weight.

Oat

Oats (Avena sativa L.) has a high content of dietary fibers compared with other cereals, various biologically active compounds (phytochemicals) such as ester linked alkyl conjugates high antioxidant activity[14]. It consists of cellulose, arabinoxylans and soluble fibers, mostly β-glucans. Oats also contain high amounts of protein and unsaturated fats [53, 54]. β-Glucans are believed to be main reason for the cholesterol-lowering effect of oats[55], in addition, it helps to control appetite and improving satiety[55, 56]. Oats contain several phenolic compounds[57] and antioxidative components including include vitamin E (tocopherols and tocotrienols)[58]. These compounds are located mostly in the outer layer of the bran fraction. All cereal grains comprise of similarly organized kernels including a hull, bran, endosperm, and germ. A hull is the outer covering that is usually removed from the grain. Figure 8. Whole grain consisting of a hull, bran, endosperm, and germ . Figure 8 shows the composition of whole grains[59].

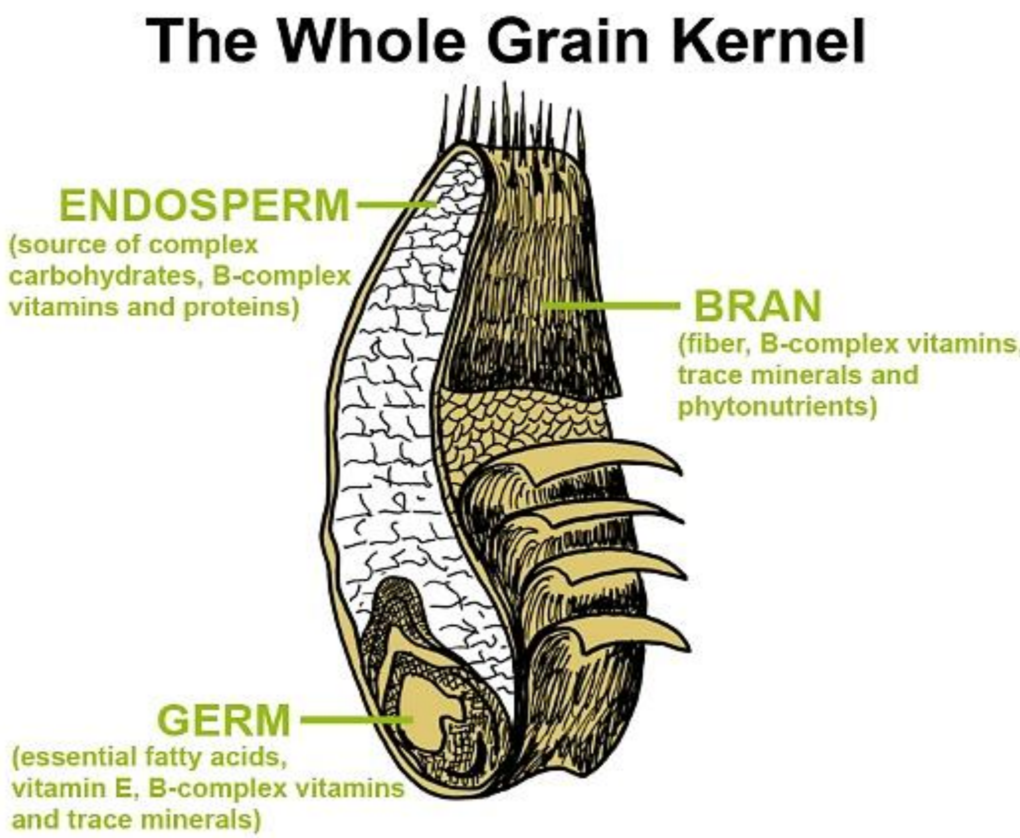


Figure 8. Whole grain consisting of a hull, bran, endosperm, and germ [59]

Most oat products are whole grains, but oat bran is just the isolated bran. The oat kernel goes through different processing to produce the different types of oatmeal Figure 9. The different forms of oatmeal [58].

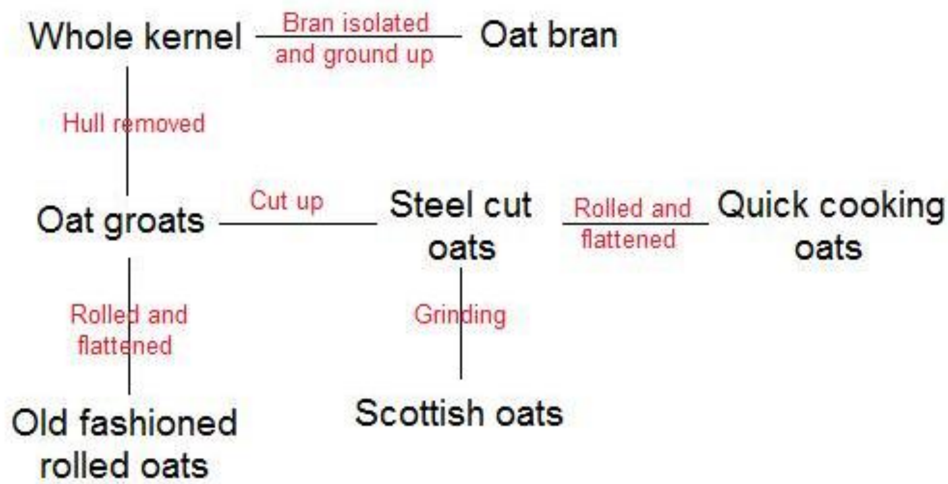


Figure 9. The different forms of oatmeal [58]

Starch makes up about 60 % of the oat grain. It is mainly located in the endosperm. The physicochemical attributes of oat starch and other cereal starches are considerably different. Oat starch shows untypical properties including small size of granules and high lipid content [57]. Oat starch possess several unique properties; the characteristics of oat starches compare with other cereal starches showed higher swelling powder, reduced amylose leaching, co-leaching of a branched starch constituents and amylose during pasting, higher point viscosity and setback, less gel rigidity, more capacity towards acid hydrolysis, greater stability to α-amylase action and high free-thaw resistance. However, it has been reported a wide range of varieties between different cultivars of oats[60, 61].

Sweet potato

The sweet potato [Ipomoea batatas (L.) Lam.] is an edible tuber with high nutritional value that contains high amounts of dietary fiber, minerals, vitamins and phenolic compounds, ascorbic acid (vitamin C), and carotenoids, (mostly trans-β-carotene like provitamin A) [62, 63]. In addition, it contains a considerable amount of starch (6.9-30.7% on wet basis) and soluble sugars. It has been reported that sweet potato starch granules are round, oval and polygonal forms and they range between 2-42 µm sizes[64, 65].

Quinoa

The main component in quinoa is made up of carbohydrates, and differs from 67% to 74% of the dry matter. Starch considers about 52–60% and is located in the perisperm of the seeds; The amylose content with 11% of weight distribution is lower than in common cereals, for instance, rice (17%), wheat (22%), or barley (26%) [51].

1.6.3 Additional Ingredients

A variety of other ingredients may be used in addition to the main ingredients. For example, dietary fiber, antioxidants, antimicrobial agents, leavening agents, emulsifiers, and combinations thereof may be included in the pre-mix. Some examples of leavening agents may include sodium bicarbonate, ammonium bicarbonate, potassium bicarbonate, mono-calcium phosphate, baking powder, cream of tartar and mixtures thereof. Antioxidant additives comprise BHA, BHT, vitamins A, C and E. The antimicrobials and antioxidants may include a combined proportion between about 0.01% to about 10%, ideally, from about 0.05% to about 5% by weight of the protein-containing materials. Some of additional ingredients are listed in Figure 10.

Additional Ingredients

- Dietary fiber
- Sodium bicarbonate
- Emulsifierl
- Sodium bicarbonate and natural antioxidants
- Sodium bicarbonate and sodium or potassium lactate
- BHA, BHT
- Natural antioxidants
- Sodium or potassium lactate
- Sodium or potassium diacetate
- Dietary fiber and sodium bicarbonate
- Dietary fiber and emulsifier
- Sodium bicarbonate and BHA, BHT,
- Dietary fiber and Sodium or potassium lactate
- Dietary fiber and Sodium or potassium diacetate
- Sodium bicarbonate and natural antioxidants

Additional Ingredients

- Sodium bicarbonate and sodium or
- potassium diacetate
- Emulsifier and BHA, BHT
- Emulsifier and natural antioxidants
- Emulsifier and sodium or potassium lactate
- Dietary fiber and BHA, BHT
- Dietary fiber and natural antioxidants
- Emulsifier and sodium or potassium diacetate
- BHA, BHT, and sodium or potassium lactate
- BHA, BHT, TBHQ and sodium or potassium diacetate
- Natural antioxidants and sodium or potassium lactate

Figure 10. Suitable examples of additional ingredients[33]

1.7 The quality problems during storage of bars

The most important quality problems during storage of bars are the following[32]:

•Color change

•Texture – bar hardening

•Loss of nutritive value

•Maillard reaction: Maillard reaction is a chemical reaction between amino groups in proteins and reducing sugars in products with water activity between 0.65 to 0.8 [32].

In most cases, high protein bars are formulated to have a water activity (aw) below 0.65 and down to 0.3. The water activity can be depressed by applying less water in the formulation and/or by using solutes with low molecular weight (humectants)[66] . Typically, the moisture content of protein bars is 10–15% w/w, and commonly sorbitol, glucose, fructose, maltodextrin, glycerol and high-fructose corn syrup are used as humectants. Protein bars have a limited shelf life due to the formation of a 'hard' or 'tough' texture that makes the product unpalatable and unacceptable during storage [8].
To have a successful protein bar its texture should acceptable. Bar hardening has an impact on the HPN bars texture as bar matrix become harder during storage[67, 68]. This problem becomes more intense when higher percentages of protein are used [67]. Texture attributes can be affected by extrinsic parameters including temperature and humidity[69] and intrinsic parameters including the structure and ingredients properties of the bar and interaction of those ingredients with each other [67, 70].

Moisture Content

Water (moisture) is the main component in many foods such as meat, milk, fruits, vegetables etc. as shown in **Error! Not a valid bookmark self-reference.** As a medium, water is the solvent where chemical reactions occur, and it is a" used" in hydrolytic reactions. consequently, removal of water from food or binding by increasing the concentration of salts or sugar make several reactions slow and prevent the growth of microorganisms, accordingly, enhance the shelf life of most foods. By means of interaction with proteins, polysaccharides, lipids and salts, water affects the texture of food [71].

Table 15. Moisture content of some foods[67]

Food	Moisture content (weight-%)	Food	Moisture content (weight-%)
Meat	65–75	Cereal flour	12–14
Milk	87	Coffee beans, roasted	5
Fruits, vegetables	70–90	Milk powder	4
Bread	35	Edible oil	0
Honey	20		
Butter, margarine	16–18		

Water activity

In 1952, Scott found that the storage quality of food depends on water activity (Aw) and not on the water content. Water activity is the water vapor pressure which is generated by the free or non-bound water in foods compare to the water vapor pressure of pure water. It is defined as follows [71]:

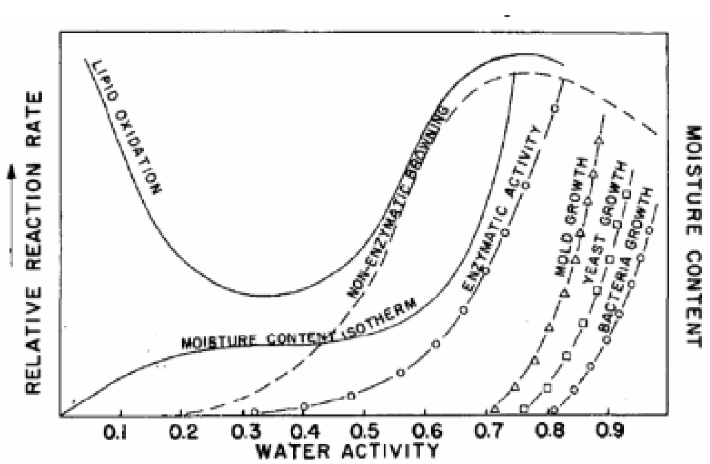
$A_w = P/P_0 = ERH/100$

P = partial vapor pressure of food moisture at temperature T

P_0= saturation vapor pressure of pure water at T

ERH = equilibrium relative humidity at T.

The water activity value is an important indicator that can influence shelf life of foods, cosmetic products and pharmaceuticals, and it strongly affects growth of microorganism Figure 11.



Water activity	Contaminant
aw = 0.91...0.95	Many bacteria
aw = 0.88	Many yeasts
aw = 0.80	Many mildews
aw = 0.75	Halophile bacteria
aw = 0.70	Osmiophile yeasts
aw = 0.65	Xerophile mildew

Figure 11. Food shelf life (storage stability) as a function of water activity [71]

Intermediate moisture foods (IMF) have aw values between 0.6 and 0.9. Intermediate moisture foods are largely preserved from the risk of microbial spoilage. Additives with high water binding capacities (humectants) are good choices that can improve the food shelf life by decreasing water activity Table 16 demonstrates that as well as ordinary salt, glycerol, sorbitol, and sucrose have potential as humectants. Moreover, some of these compounds such as glycerol and sorbitol may act as sweeteners and it would be not acceptable from a consumer point of view in many foods in the percentages that they are required to control water activity[8].

Table 16. Moisture content of some food or food ingredients at a water activity of 0.8 [1]

	Moisture content (%)		Moisture content (%)
Peas	16	Glycerol	108
Casein	19	Sorbitol	67
Starch (potato)	20	Saccharose	56
		Sodium chloride	332

Water activity is not the only indicator to consider regarding the storage life of foods with a low water content since water activity illustrates the ideal, i.e. very dilute solutions in the thermodynamic equilibrium state. Based on phase transition which explains the effect of water interaction and hydrophilic ingredients during storage, the physical properties of food must also be considered to predict shelf life better.

The physical state of foods relies on food composition, temperature and storage time. For instance, related to the temperature, the phases could be glassy, rubbery or highly viscous and if hydration of hydrophilic components of food happens, food phase changes to plastic. So, the water content has an impact on the temperature T_g (phase transition temperature)[8].

1.8 Extrusion of materials

the ingredients functional attributes, the equipment selection, process line and system variables that applied in the producing process indicate the physical quality of a product, Figure 12 shows that, based on the objectives of the manufacturer ,the relation between characteristics of raw materials, process variables, subsequent system factors and changes in the food ingredients will set, however, altering of a parameter in one variable does not represent directly who can impact on another parameter[53].

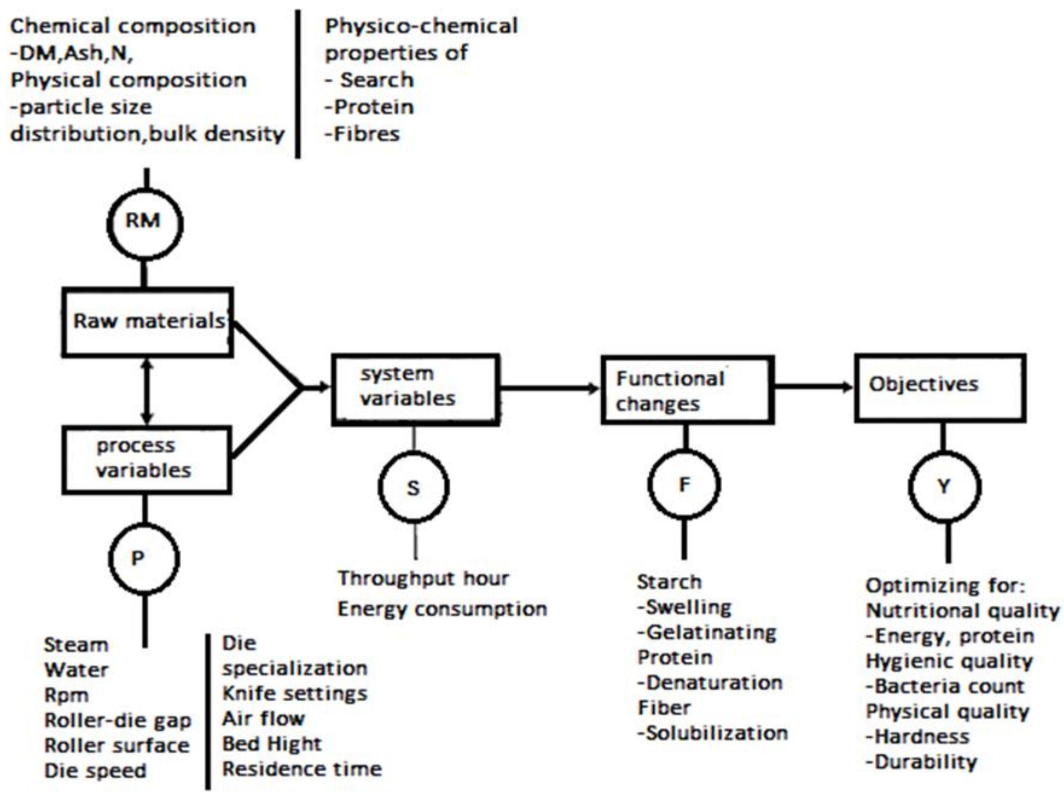


Figure 12. Schematic display based on the objectives of the manufacturer connection between attributes of raw materials, process variables, subsequent system parameters and changes in the food ingredients will set [53]

During extrusion, due to various types of protein structure based on the constituent amino acids, it is difficult to specify the consequence of transformation and re-structure of the molecules[72]. Extrusion cooking has an impact on the gelatinization properties of starch, cross-linking and polymerizing of proteins and starch to form expanded matrices[73]. If the temperature is high enough the unfolding of proteins, hydrolyzing and denaturation will happen during the extrusion. In addition, the formation of complex matrices with the degree of expansion rely on concentration of protein.

The textural quality of extrudates, as well as cross-linking between protein and starches are increased by rising the concentration of protein[74]. The protein structural changes happens during the extrusion Figure 13 .The expansion and texture of the extrudate are also related to the interaction of shear, heat, and moisture of the ingredients in the extruder[75]. The screw configuration, speed rate, and the addition of reverse screw elements rise the shear and control the energy distribution such as melting temperature, torque, and pressure. The puffing degree/expansion is determined by the melting temperature[76]. Controlling the process responses such as SME effectively increases the expansion, which affects the crispiness of the expanded products[77]. The moisture has a great influence on the quality of extrudate, especially fragility of the expanded products[78, 79]. The physical and sensory qualities of the extrudates are significantly dependent on the protein concentration, moisture content, physical and mechanical condition during extrusion.

Generally, the breakfast food and snack extrudates comprise of high percentages of starches including oat, corn, wheat, tapioca, rice, potato, or other sources. Commonly, in expanded extrudates, the percentage of proteins are lower than the percentage of starch to promote expansion, crispiness, and enhance bulk density.

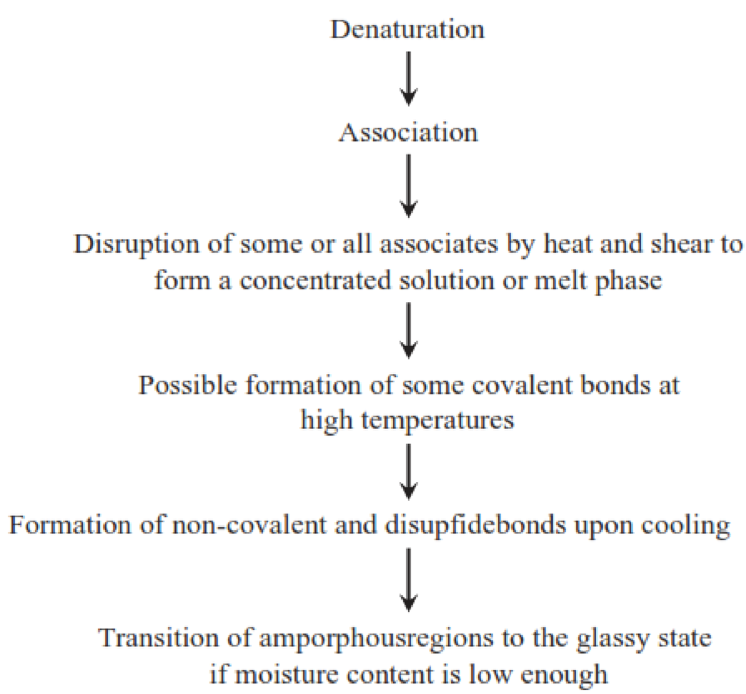


Figure 13. Protein structural changes occurring during the extrusion (adopted from Mitchell and Areas 1992)[70]

2 Material and Method

This study relates the composition of high protein bars and applying two technologies; extrusion and baking technology, five different recipes with different compositions based on a literature study of existing products, were prepared before selecting the final compositions of the main experiments.

2.1 A Literature survey of commercial bars on the market

To have a proper overview of processing, formulation, ingredients, market acceptability and nutritional value of protein bars, several commercial protein bars give important information to this study Some of these are shown in Table 18. The most common types of sweeteners and proteins that are used are shown in Table 19 and Table 38 (appendix) and these data were collected from the literature and website of MATVARETABELLEN[80] and the product labels.

The wide range of ingredients used in different commercial bar, the most common ingredients in protein bars are soy and whey protein. Food bar differ in serving size, type of bar including meal replacement and snack, or the concentration of protein content etc.

Table 17. The popular commercial bars properties

Bar name	Type of bar	Serving size (g)	Energy (kcal) per100 g	Nutrient composition (%)			
				Protein (g)	Fat (g)	Carbo-hydrate (g)	Fiber (g)
MACRO BAR	Meal Repl. *	71	290	15	18	39	3
PROBAR MEAL	Meal Repl.	85	350	9	17	47	6
RISE PROTEIN BAR	Meal Repl.	60	280	20	16	20	4
KATE'S REAL FOOD	Meal Repl.	85	360	9	14	51	6
BOBO'S OAT BARS	Meal Repl.	85	280	4.5	12	40.5	3
CLIF BAR ORIGINAL	Meal Repl.	68	240-260	5	10	44	5
CLIF BUILDER'S BAR	Meal Repl.	68	270	20	8	38	6
NRG BAR	Meal Repl.	71	250	6	4.5	46	3
MACRO BAR	Meal Repl.	71	290	15	18	39	3
VEGA SPORT	Snack	60	240	15	7	30	3
CLIF MOJO	Snack	68	240	10	5	43	5
LUNA BAR	Snack	48	180	9	5	38	3
NUGO ORGANIC	Snack	45	190	9	5	27	4
POWERBAR	Snack	65	240	8	3.5	45	1
KIND	Snack	40	210	7	12	14	4
YT	Energy	55	364	6.2	5.4	70	5.1
BONK BREAKER	Snack	62	220	6	5.5	37	6
TASTE OF NATURE	Snack	40	200	5	11	19	2
AMAZING GRASS WHOLE FOODS BAR	Snack	60	210	5	8	35	5
CLIF CRUNCH GRANOLA BAR	Snack	42	190	5	9	25	3
LARABAR	Snack	45	200	4	8	30	4
NATURE VALLEY GRANOLA BAR	Snack	42	190	4	6	28	2
PROBAR FRUITION	Snack	48	160	3	3	33	4
MACROBAR	Snack	57	220	3	6	38	3
RISE ENERGY BAR	Snack	45	190	3	9	27	3
Quest Bar White Chocolate Raspberry	Snack	60	200	20	8.4	6	14
Protein bar chocolate	Snack	55	388	18	5.5	23.6	0.6

Table 18 Different protein and sweetener sources of different comercial bars

Product specs	Category	Protein source	Sweetener
Probar meal	Meal repl.	Org nuts & seeds	Evap cane juice, rice, molasses
Taste of nature	Snack	Organic nuts & seeds	Organic agave, & brown rice syrup
Kate's real food	Meal repl.	Organic peanuts	Organic honey
Larabar	Snack	Almonds, walnuts	Dates, fruit
Macrobar	Meal repl.	Organic nuts & seeds	Evap cane juice, rice, molasses
Probar fruition	Snack	Organic raw cashew	Org date, rice
Macrobar	Snack	Organic sesame seeds & rice protein	Organic brown rice syrup, organic raisins & dates
Rise protein bar	Meal repl.	Almonds, whey protein isolate	Honey, agave
Nrg bar	Meal repl.	Pumpkin seeds	Fig & date paste
Bobo's oat bars	Meal repl.	Organic oats & pb	Brown rice syrup
Clifbar original	Meal repl.	Organic almonds, pistachios, walnuts	Organic dried cane syrup, sugar, raisins
Rise energy bar	Snack	Almonds, amaranth	Organic brown rice syrup, organic fruit
Amazing-grass whole foods bar	Snack	Organic cashews & almonds, & seeds	Organic agave
Bonk breaker	Snack	Brown rice protein- non-gmo	Brown rice syrup, honey
Clif mojo	Snack	Soy, nuts	Evaporated cane syrup, rice
Clif-crunch granola bar	Snack	Peanut butter	Dried cane syrup, barley malt extract, honey
Luna bar	Snack	Soy protein isolate	Organic dried cane syrup & brown rice syrup
Clif builder's bar	Meal repl.	Soy protein isolate, dry roasted almonds.	Beet juice, brown rice syrup, cane juice
Kind	Snack	Nuts	Honey
Vega sport	Snack	Sprouted brown rice & pea	Dates, sorghum syrup
Nugo organic	Snack	Rice protein crisps, almonds, pumpkin & flax seed	Brown rice syrup, organic agave syrup
Powerbar	Snack	Soy, nuts, dairy	Evaporated cane syrup, fructose, dextrose
Nature-valley granola bar	Snack	Oats, corn & soy flour	Sugar, brown sugar syrup, honey

2.2. Pre-experiment of producing baked and extruded protein bars

The procedure for baked bars in pre-experiment consisted of mixing dry and wet ingredients separately, then all were mixed Figure 14.

2.2.1 Different ingredients of the pre-experiment

Different sources of ingredients of oil, protein, starch, flavor and sweetener were used to find an optimal combination of taste and flavor (Figure 14). Bars were formulated using WPC 80% as the main protein source with different carbohydrate sources and other ingredients Table 19.This resulted in five bars with different ingredients and nutritional values Figure 15. The same procedure was used for mixing and formulating of the extruded bars.

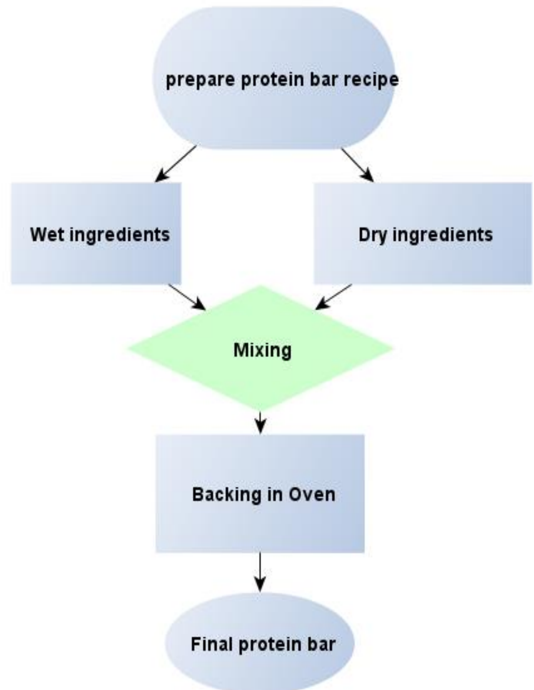


Figure 14. Formulation procedure for baked bars

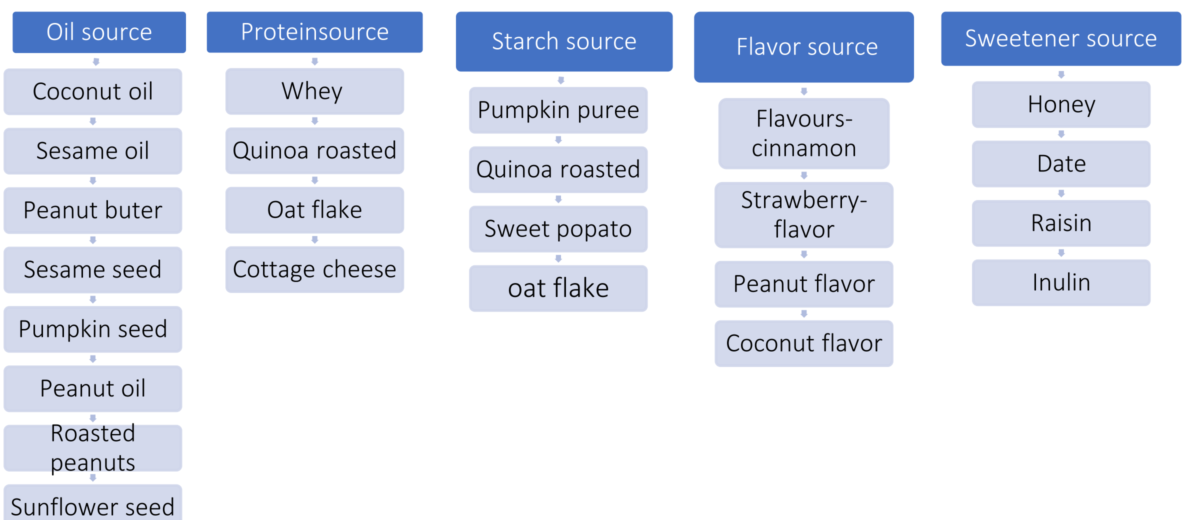


Figure 15. Sources of ingredients of the pre-experiment

Table 19. A detailed overview of the ingredients, their supplier and their amount (given in percent of total) used in the five baked bars. Ingredient are grouped according to type.

Type of ingredients	Ingredients	Supplier	Recipe (Number and Name)				
			1	2	3	4	5
			Pumpkin	Sweet potato	Oat	Coconut-Stevia	Glycerin - Sukri
Dairy	WPC 80	TINE	0.37	0.32	0.25	0.3	0.3
	Cottage cheese	TINE	0.09	0.1	0.05	0.1	
Cereals, seeds and nuts	Oat flakes	AXA			0.2	0.25	
	Quinoa boiled	GOGREEN	0.05				0.18
	Quinoa roasted	GOGREEN		0.16	0.05	0.05	0.18
	Sunflower seeds	GOECO	0.05				
	Pumpkin seeds	GOECO	0.02			0.02	0.027
	Sesame seeds with shell	GOECO			0.02	0.02	
	Roasted peanuts	POLLY		0.03			
	Peanut butter	PEANOTTSMOR		0.071	0.05		0.07
Oils	Coconut oil	GREEN CHOICE	0.03			0.02	
	Peanut oil	International oil collection			0.03		0.03
	Sesame oil	NATURATA	0.02		0.27 5	0.02	
Fruits	Pumpkin puree	LIBBYS	0.28			0.08	0.14
	Sweet potato	REMA		0.15			
	Dried apples	MENY		0.04			0.05
	Raisins	ELDERADO	0.05	0.03			0.03
	Dates	MENY		0.05			
Sweetener	Honey	HONNING	0.06		0.03	0.07	
	Inulin	ENERGYBALANCE		0.04	0.04		
	Sukri	SUKRILETT					0.07
	Stevia	BIOPHARMA				0.067	
Humectant	Glycerin						0.10
Flavor	Cinnamon	SANTAMARIA	0.01	0.006			
	Strawberry	GO Johnsen AS			0.00 5		
	Peanut	MENY					0.003
	Coconut	GREENCHOICE				0.003	
	SUM		1.00	1.00	1.00	1.00	1.00

Table 20. The five bars with different nutritional information [61]

Type of ingredients	Ingredients	Supplier	Energy (kcal)	Nutrient composition (%)					Dry matter
				Fat	Starch	Sugar	Dietary fiber	Protein	
Dairy	WPC 80	TINE	406	8	0	5.5	0	78	91.5
	Cottage cheese	TINE	79	2.0	0	2.1	0	13	17.1
Cereals, seeds and nuts	Oat flakes	AXA	373	7	60.4	1.3	11.7	13	93.40
	Quinoa boiled	GOGREEN	144	2.4	21	2.4	2.8	5.7	34.3
	Quinoa roasted	GOGREEN	358	6.1	52.2	6.1	7	14.1	85.5
	Sunflower seeds	GOECO	630	51.5	16.3	1.7	6	20.8	96.3
	Pumpkin seeds	GOECO	630	51.5	16.3	1.7	6	20.8	96.3
	Sesame seeds w shell	GOECO	672	61.0	4.10	0.00	11	20	96.1
	Roasted peanuts	POLLY	623	51	4.70	4.80	9.5	26.7	96.70
	Peanut butter	PEANOTT-SMOR	651	55	0	14.0	6.2	22	97.20
Oils	Coconut oil	GREEN CHOICE	900	100	0	0	0	0	100
	Peanut oil	Internationa l oil collection	828	92.0	0	0	0	0	92
	Sesame oil	NATURATA	900	100	0	0	0	0	100
Fruits	Pumpkin puree	LIBBYS	33	0	0	11	4	2	17
	Sweet potato	REMA	80	0.00	12.6	4.20	3	1.6	21.40
	Dried apples	MENY	364	0.50	0.00	81.2	13.7	2	97.40
	Raisins	ELDERADO	316	0.70	0.00	76.9	5.8	3	86.4
	Dates	MENY	299	0.20	0.00	68	6	3.3	77.50
Sweetener	Honey	HONNING	334	0.00	0	80	0	1	81
	Inulin	ENERGYBAL ANCE	150	0.00	0.00	8.00	92	0	100.0
	Sukri	SUKRILETT	0	0	0	100	0	0	100
	Stevia	BIOPHARMA	0	0	0	100	0	0	100
Humectant	Glycerin		400	0	0	90	0	0	90
Flavor	Cinnamon	SANTAMARI A	247	1.24	0	0	53.1	3.99	58.33
	Strawberry	GIVAUDAN	0	0	0	0	0	0	0
	Peanut	GIVAUDAN	0	0	0	0	0	0	0
	Coconut	GIVAUDAN	0	0	0	0	0	0	0

2.3Main Experiment

2.3.1 Materials

Whey Protein concentrate (WPC80) and cottage cheese were obtained from TINE company. The rest of ingredient and company's producer are shown in Table 19.

2.3.2 Formulation

From the pre-experiment two formulation of ingredients were selected for the main experiment. This was pre-experiment **no. 3. Sweet potatoes** and **no. 4. Oat** specified in Table 19. Two processing techniques were used to produce the bars; baking and extruding techniques. The formulation for producing the extruded protein bars are shown in Table 21 and for preparing the baked bars are shown in Table 22.

Moisture content and water activity were analyzed before and after extrusion. In addition, a sensory panel (panelist and students) were used to evaluate flavor, appearance, hardness, textures, and other attributes to characterize acceptability of the final high protein bars. Table 21 shows the weight distribution and physical properties of different ingredients of the extruded bars.

Table 21. Formulation of ingredients of the extruded bars

Ingredients	% weight distribution	Kcal/gr	fat	Starch	Sugar	dietary fiber	protein	dry matter
Whey	41,9	406	8,00	0	5,5	0	78	91,50
Quinoa roasted	14,7	358	6,10	52,2	6.1	7	14	85,40
Cottage cheese	2,5	79	2	0	2.1	0	13	17,10
Oatmeal	11,3	373,0	7,0	60,4	1.3	11,7	13	93,40
Coconut oil	2,4	900	100	0	0	0	0	100
Sesame oil	0,4	900	100	0	0	0	0	100
Sesame seed	0,7	672	61	4,10	0	11	20	96,10
Sunflower seed	2,3	630	51,5	16,3	1.7	6	20,8	96,30
Peanuts, roasted	2,3	623	51	4,7	4.8	9,5	26,7	96,70
Dried fruits	5,7	50	0,4	7,4	6,2	6,3	1	21,30
Raisin	1,8	316	0,7	0	77	5,8	3	86,40
Glycerin	5,5	400	0	0	90	0	0	90
Stevia	4,5	0	0	0	100	0	0	100
Honey	2,1	334	0	0	80	0	1	81
Baking powder	0,1	53	0	8	0	1	0	9
Flavors-cinnamon-coconut	0,01	0	0	0	0	0	0	0

The second main experiment was the baking method with the different ingredients and weight distribution as shown in Table 22.

Table 22. Formulation of ingredients of the baked bars

Ingredients	% weight distribution	Kcal/gr	Fat	Starch	Sugar	Dietary fiber	Protein	Dry matter
Whey	0.30	406	8	0	5.5	0	78	91.5
Quinoa roasted	0.23	358	6.10	52.2	6,1	7	14	85.4
Cottage cheese	0.09	79	2	0	2,1	0	13	17.1
Sweet potato	0.06	85.0	0	13.4	4,5	3.2	1.7	94
Coconut oil	0.04	900	100	0	0	0	0	100
Sesame oil	0.01	900	100	0	0	0	0	100
Sesame seed	0.01	672	61	4.10	0	11	20	96.1
Pumpkin seed	0.03	560	45.6	14.2	0	8.8	24.4	93
Almonds	0.03	577	49.2	2.4	3,9	12.2	21.2	88.9
Dried fruits	0.03	50	0.4	7.4	6.2	6.3	1	21.3
Raisin	0.02	316	0.70	0	77	5.8	3	86.4
Glycerin	0.09	400	0	0	90	0	0	90
Stevia	0.03	0	0	0	100	0	0	100
Honey	0.04	334	0	0	80	0	1	81
Salt	0	0	0	0	0	0	0	0
Baking powder	0	53	0	8	0	1	0	9
Flavors-cinnamon-coconut	0	0	0	0	0	0	0	0
Total	100	351.1	11.6	13.41	16.18	2.73	29.08	
Serving size	60.0	210.6						

2.3.3 Preparation of ingredients for mixing

To produce the two types of a protein bars, baked and extruded, some ingredients needed a pre-treatment:

- Quinoa was roasted inside oven by 180̊ c temperature for 10 minutes.
- Half amount of oat flake was grinded to make it more starch-accessible in extrusion process.
- Sunflowers seed and peanut seeds were grinded little bit to become suitable size for extrusion.
- Cottage cheese was blended with powerful mixer to make it homogenize and the glycerol and honey was then placed in the blender to mix with wet ingredients.
- Sweet potato was dried to reduce the moisture content of final recipe

- Twin shaft mixer (Forberg, Oslo, Norway) was used to mix all ingredients together to obtain a uniform mixer.

2.3.4 Equipment

The following equipment were used Table 23:

- A blender, Twin shaft paddle mixer, was used to mix the ingredients before extrusion.
- A twin-screw extruder was used for the extrusion with different extrusion temperatures, kept at the same temperature for the last four zones before the die,
- Approximately 7%, 9%, 11% moisture content of the mixture,
- A fan dryer,
- Water activity analyzer,
- Moisture analyzer
- Hardness analyzer
- Freeze dryer
- Oven,
- Microwave,

Table 23. Equipment used during experiment

Name of equipment	Type specifications
Twin-screw extruder	Buhler twin screw extruder (ex 50/134 l, UZWIL, Switzerland)
Twin shaft paddle mixer	FORBERG, Oslo, Norway
Dryer	Fan driven dryers of steel -developed at the Center for Feed Technology
Water activity analyzer	Rotronic water activity systems
Moisture analyzer	Sartorius MA100, Sartorius AG, Gottingen, Germany
Freeze dryer	DW 6-85
Oven	Electrolux
Microwave	Electrolux
Hardness analyzer	Amandus Kahl, GMBH & Co. KG, Hamburg, Germany
Blender	Waring-commercial
Food-processor-Mixer	Coline -CW1299

2.3.5 Processing

2.3.5.1 Processing Procedure

The first days the dry ingredients were weighed and grinded in a food processor and wet ingredients were homogenized (cottage cheese and honey and oil), due to tow different recipes, there were two different mixing time. Dry component added to a blend mixer and the contents were mixed until they were homogeneous and formed a dry blended pre-mix. The mixture of liquid ingredients was added to dry blended pre-mix to modify the product formulation. The different ingredients were then mixed in a modified twin shaft mixer (400 L, Tatham, Rochdale, UK) for 15 minutes. Blending times using dry components are mostly short (15-30 minutes) but are to some extent relate upon the differing percentages of each ingredient, and the variation of the bulk densities of each. Although it has been pre-experiment in the laboratory in small amount, the sweet potato recipes were not quite suitable to run extruder.

At day two, during mixing of second recipe, when the wet ingredients were manually sprayed over the dry ingredients, due to formation of lumps it has been decided the second recipe to be backed inside oven instead of extrusion cooking. Therefore, it has applied two different methods for producing high protein food bar. The mixture is then fed manually to a twin-screw extrusion at a rate of not more than 5 kg/h.

Figure 16. Tween shaft mixer

2.3.5.2. Extrusion methods

Among the useful extrusion systems suitable for use, in this current experiment a twin-screw extruder was used to prepare the extruded protein compositions of the experiment. The mixture was fed manually to a head Buhler twin screw extruder (Ex 50/134 L, Uzwil, Switzerland), with a length: diameter ratio of 20:1 at a rate of not more than 5 kg/h. At the outlet of the extruder, the die was fitted with one circular inserts, with12 mm in diameter for producing the food bars. Water was added through an electromagnetic dosing pump at the rate of 7%, 9 %,11%, 11% kg/h, at the third zone. The extrudates were dried after extrusion.

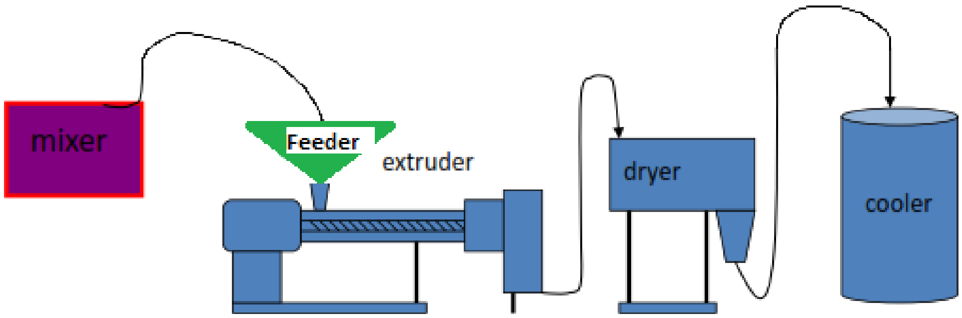


Figure 17. Schematic of extrusion prosses [81]

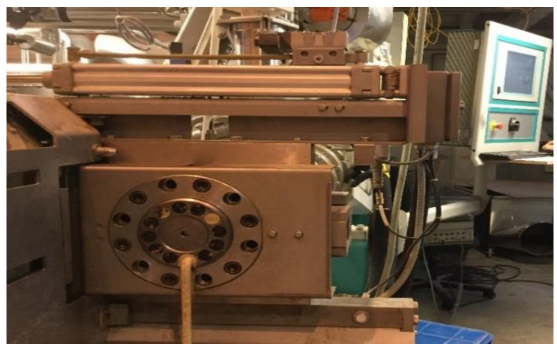


Figure 18. The extruder used in this study.

The parameters for the extruder during the processing of the food bar are presented in Table 24 (parameters obtained manually from Buhler monitor). Figure Screw configuration was modified a standard mild SME input screw configuration from FôrTek.

2.3.5.3 Process conditions

Three extrusion conditions were evaluated: (1) low shear extrusion at 9,11% kg/h moisture input; (2) high shear extrusion at 11% kg/h moisture input; and (3), high shear, low moisture 7%kg/h extrusion.it has shown Table 24 Parameters for the extruder during processing (the data were obtained manually).

Table 24. Extrusion parameter during processing

Sample Number	No.0	No.1	No.2	No.3
Die size	12	12	12	12
Number of dies	2	2	2	2
Feeder (kg/h)	5h	5h	5h	5h
Section 1	37.6	38.9	38.6	39.3
Section 2	91.4	64.6	73.7	80.1
Section 3	110.4	109.1	102.1	109.5
Section 4	112.6	109.8	107.4	109.2
Section 5	106	107.5	105.9	108.2
Die temperature °C	88	91	93	97
Die pressure (bar).	2.4	1.8	1.6	1.1
Pressure, section 4	0.56	0.23	0.2	0.33
SME (Wh/kg)	1.73	0.82	0.73	1.28
Torque (Nm)	193	133	124	114
Torque (Relative, %)	44	31	28	26
Drive power (kW)	9.3	4.5	4.1	7.2
Screw speed (rpm)	397	321	321	625
Extra. Water (%)	7	9	11	11
Extra. water (kg/h)	0.37	0.49	0.61	0.61

2.3.5.4 Backing methods

The second method to produce a bar was baking in an oven (Figure 19 and 20). In order to decreasing moisture content two different procedure were applied. First, freeze drying was performed to reduce the moisture content of the mixture. Then backing in the oven was performed at two different temperature 50^0C and 100^0C.

Figure 19. Baking processing of the protein bars

Figure 20. Baked protein bars

2.3.5.5 Drying- after extrusion

Generally, the extrudate produced in extruder, is dried to decrease moisture content of the final product to the desired rate. The final product will be staying in the dryer until the desired moisture content. Thus, the temperature of the airflow is not significant, for instance, longer drying times needs in a lower temperature than the higher temperature. As soon as the extrudate dried, typically its moisture content ranged from about 4% to about 15%. The protein bar was dried in small experimental dryers (fan driven dryers of steel) developed at the Center for Feed Technology. Drying lasted approximately one day before rapid analysis of moisture content was conducted.

Figure 21. dryer in extrusion processing

2.3.5.6 Freeze drying – in backing method

Freeze drying, also known as cryodesiccation, Freeze-drying functions by freezing the material and then decreasing the surrounding pressure to which it forces the frozen water in the material to be sublimated from the solid phase to the gas phase directly[82]. Freeze-drying (blue arrow) brings the materials around the triple point, prevent the direct liquid-gas transition seen in ordinary drying time (green arrow) Figure 22[82]. In a lab, this is often applied by placing the material in a freeze-drying flask Figure 23.

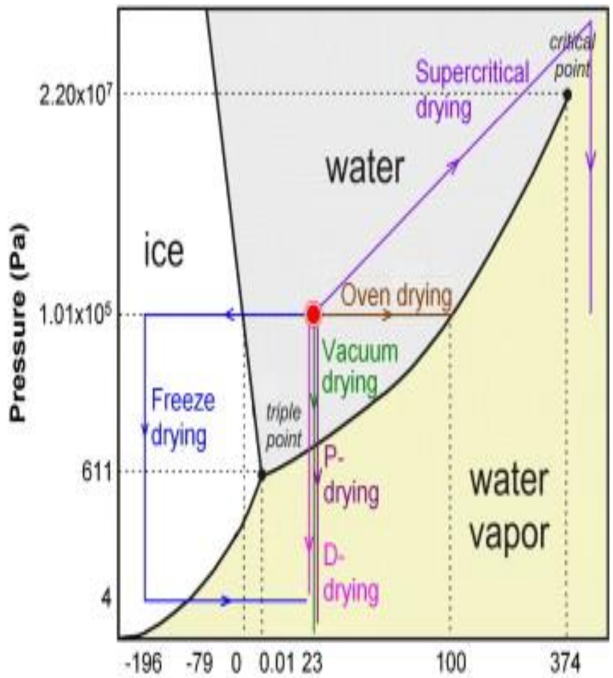


Figure 22. Freeze-drying functions

Figure 23. Freeze drying of samples

2.4. Analysis of the products

2.4.1 Analysis of moisture content

The water content of samples of three different conditions in extruder was determined by crushing 9 food bar samples and placing the crushed food bars in Electronic Moisture Analyzer (Sartorius MA100, Sartorius AG, Gottingen, Germany) for rapid analysis of moisture content[83].

Figure 24. Electronic Moisture Analyzer

2.4.2 Hardness (strength at rapture)

Hardness was measured using an Amandus Kahl hardness tester (Amandus Kahl, GmbH & Co. KG, Hamburg, Germany). The tester showed the applied pressure at fracture in kg. The hardness analysis was conducted on samples from different conditions during extrusion.

Figure 25. Hardness Tester[84]

2.4.3 Water activity

Water activity was measured by Rotronic Water Activity Systems. The principle for measuring Aw are following[85]:

- It must have static equilibrium
- having the same temperature for the product, the instrument, and the environment
- having the same partial pressure of water vapor in the environment and in the product.

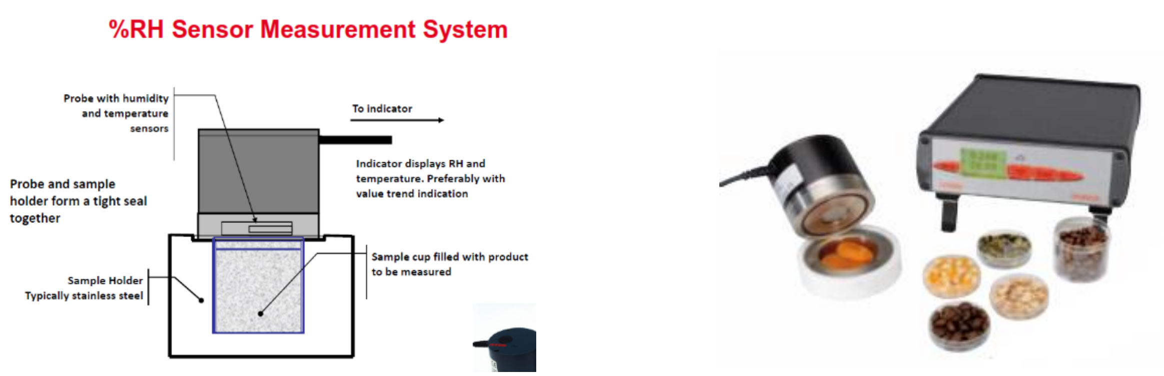


Figure 26. %RH Sensor Measurement System[86]

2.4.4 calculations of specific mechanical energy (SME) and expansion ratio

For calculating of SME, drive power will be divided to throughput, and expansion ratio is a difference of diameter of product and die size per die size diameter.

$$SME = \frac{\text{Screw speed} \cdot \text{torque}}{\text{Throughput}} = \frac{\text{Drive power}}{\text{Throughput}}$$

$$\text{Expansion ratio} = \frac{\text{Pellets diameter} - 12\text{mm (die size)}}{12\text{mm (die size)}} \cdot 100\%$$

2.4.5 Nutritional value

The calorie and nutrient content of the final samples was calculated based on the USDA's National Nutrient Database and information from the manufacturer and literature. No chemical analyses of the samples were done to confirm the quantity. Therefore, this information are only theoretical values.

2.4.6 Sensory evaluation

2.4.6.1 Sensory evaluation – a comparison between extruded, baked and commercial bars

Sensory analysis techniques (descriptive, discriminatory, and affective tests) are usually applied to evaluate food sensory. Since it was not applicable to do a testing consisting of many consumers, a selected panel of 8 persons (panelists) evaluated the bars. Panelists tested two commercial protein bars and the baked and extruded bars. The two commercial protein bars were: 1. PROTEINBAR, a chocolate bar Figure 29 and 2. QUESTBAR Figure 30.Eight untrained panelists (1 males and 7 females) tested the bars A List of words that described the bars in terms of appearance, aroma, texture, and flavor attributes were presented. Overall, appearance, texture, and flavor acceptance were evaluated using a 4-point hedonic scale (where 4= the most like and 1= the most dislike) as indicated in the question sheet presented below Figure 27.

Sensory evaluation panel

Sensory evaluation is the evaluation of the sensory properties of high protein food bar (appearance, flavor, and texture)

The ranking test is valuable when several samples need to be evaluated for a single characteristic. Ranking test procedures have the advantage of simplicity in instructions to panelists, ease of data handling, and minimal Assumptions about the level of measurement because the data are ordinal.

- It can be carried out by the following steps:
  1. **look at the food** and describe the overall **appearance**
  2. **smell the food** and describe **its aroma**
  3. **cut the food** and **feel its texture**
  4. **chew the food** and describe the **taste and mouthfeel**

Please test each of the code samples in the set in the sequence presented, rank the 4 samples in descending order of properties. You may re-taste any of the samples while ranking for intensity of the properties. No ties are allowed in the ranking. Rinse your mouth with water between samples, and wait for 30 seconds before you taste the next sample.
Remember that the most intense sample should be ranked 1.

	Appearance/color	Taste/Flavor	Smell/Odor	Texture/Mouthfeel
Sample1				
Sample 2				
Sample 3				
Sample 4				

Figure 27. The question sheet of Sensory evaluation

Figure 28. Bar no. 1-extruded bar, 2. Backed bar, 3. Commercial bar name chocolate Protein bar 4. Commercial bar, name Quest bar

The commercial bar with the name **Protein bar** and with the following ingredients:
Milk protein, fructose-glucose syrup, milk chocolate (sugar, cocoa butter, milk powder, cocoa mass, emulsifier (soya lecithin), flavoring), whey protein (containing milk), rice flour, emulsifier (soya lecithin), maltitol syrup, humectant (glycerol), cocoa powder, salt, emulsifier (soya lecithin), flavoring.

Figure 29. The chocolate Protein bar

The commercial bar with the name Quest bar and with the following ingredients
Protein Blend (Milk Protein Isolate, Whey Protein Isolate), Soluble Corn Fiber (Prebiotic Fiber), Almonds, Water, Cocoa Butter, Dried Raspberries, Natural Flavors, Erythritol, Palm Oil, Sea Salt, Calcium Carbonate, Sucralose, Steviol Glycosides (Stevia).

Figure 30. Quest bar

2.4.6.2 Sensory evaluation - Consumers acceptability

A number of questions were raised to collect data of consumer's acceptability of snacks protein bars (Figure32). Questions and sensory evaluation of the baked bar and the extruded bars was done by **20 students at IKBM**. There were asked several questions to have an overview of customer behavior and attitude towards food selections.

Figure 31. sample1 extruded bars sample 2 baked and -The sample in the middle is the ingredients

2.4.6.3 Statistics of the Sensory profile

The samples were evaluated in a sensory profile, similar to qualitative descriptive analysis (QDA) to evaluate differences among high protein bar products and to determine their relationship to consumer acceptability through SPSS Statistics V22 (statistical Calculations) and statistics were calculated in the same program and excel. The Tukey-Kramer adjusted P-value ($\alpha = 0.05$) was used to determine differences between the least squares means. Levene's statistic: this test is designed to test the null hypothesis that the variances of the groups are the same. If significance value (p-value) is greater than 0.05 (found in Sig.column), then you have homogeneity of variances.in other words, the variances between the two groups are equivalent or not significantly different.

Sensory evaluation for the high protein commercial bars

1- **Frequency of snack-food-bar purchasing;**

two times a year or less ☐	once a month ☐	once a week ☐	more than 3 times a week ☐

2- **Which of the following are VERY important to you when choosing a natural protein bar? (Check all that apply...)**

Price ☐	Taste ☐	Texture ☐	High energy ☐	High protein ☐	Qualifies as vegan ☐

3- **How do you typically judge a food bar or protein bar? judgefoodbar**

		Agree	Neither agree nor disagree	Disagree
1	A healthy diet is very important to me.			
2	I want to know the nutritional quality of snack before buying it			
3	I would choose snacks fortified with protein.			
4	I would choose snacks with less fat.			
5	I would choose snacks containing less trans-fat			
6	I never pay attention to the list of ingredients of snacks before buying it.			
7	I would encourage my kid(s) to consume snacks fortified with protein rather than regular snack.			

4- **What do you like about these two samples? (Please write a number)**

Like – No 4 - neither like nor dislike-No3 - Dislike-No2

	Appearance/color	Taste/Flavor	Smell/Odor	Texture/Mouthfeel
Sample1				
Sample 2				

5- **Which one do you like the most?**

Sample 1 ☐ sample2 ☐

6- **How often you do workout per year?**

two times a year or less ☐	once a month ☐	once a week ☐	more than 3 times a week ☐

7- **Gender**

Female ☐	Male ☐	Prefer not to answer ☐

8- **Your age?**

under 18 ☐	18-25 ☐	26-35 ☐	36-45 ☐	Prefer not to answer ☐

Thank you for your responses! If you have any other comments about snacking, feel free to provide them, here.

Figure 32. sensory evaluation questions

3.Results

3.1 A literature survey of bars on the market

3.1.1 Energy and protein bars available on the market

The nutrition information of different commercial bars that have been reviewed and the results are shown in Figure 32. The highest protein contents are found in Cliff builders bar and in Rise protein bar, both with 20 g protein per serving (40-60 g). The other commercial bars do not have remarkable high protein content (< 10%), except for MacroBar and Vegasport with 15% protein content. These are mostly used as energy bars, since the amounts of carbohydrate are most prominent. The bar with the highest energy contents Figure 33 are Kate's Real Food bar, ProBar and Tine YT bar with approximately 360 kcal per 100 g, which must be considered as a meal replacement category (> 250 Kcal per gram).

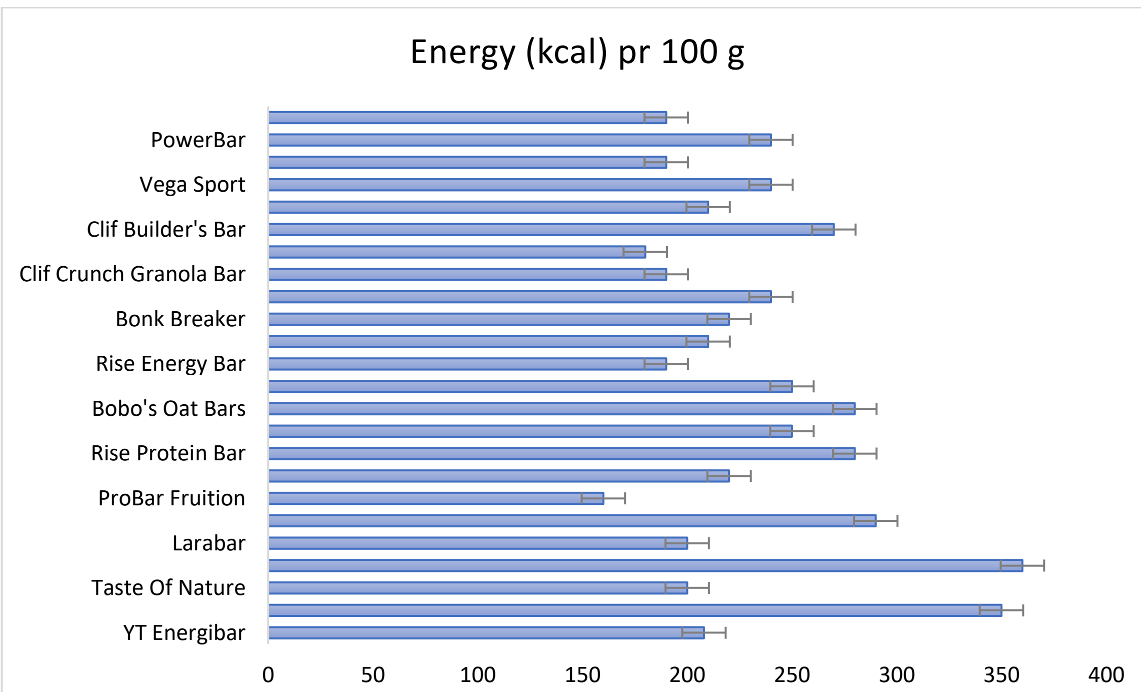


Figure 33. Energy (Kcal) pr. 100 g in different commercial bars

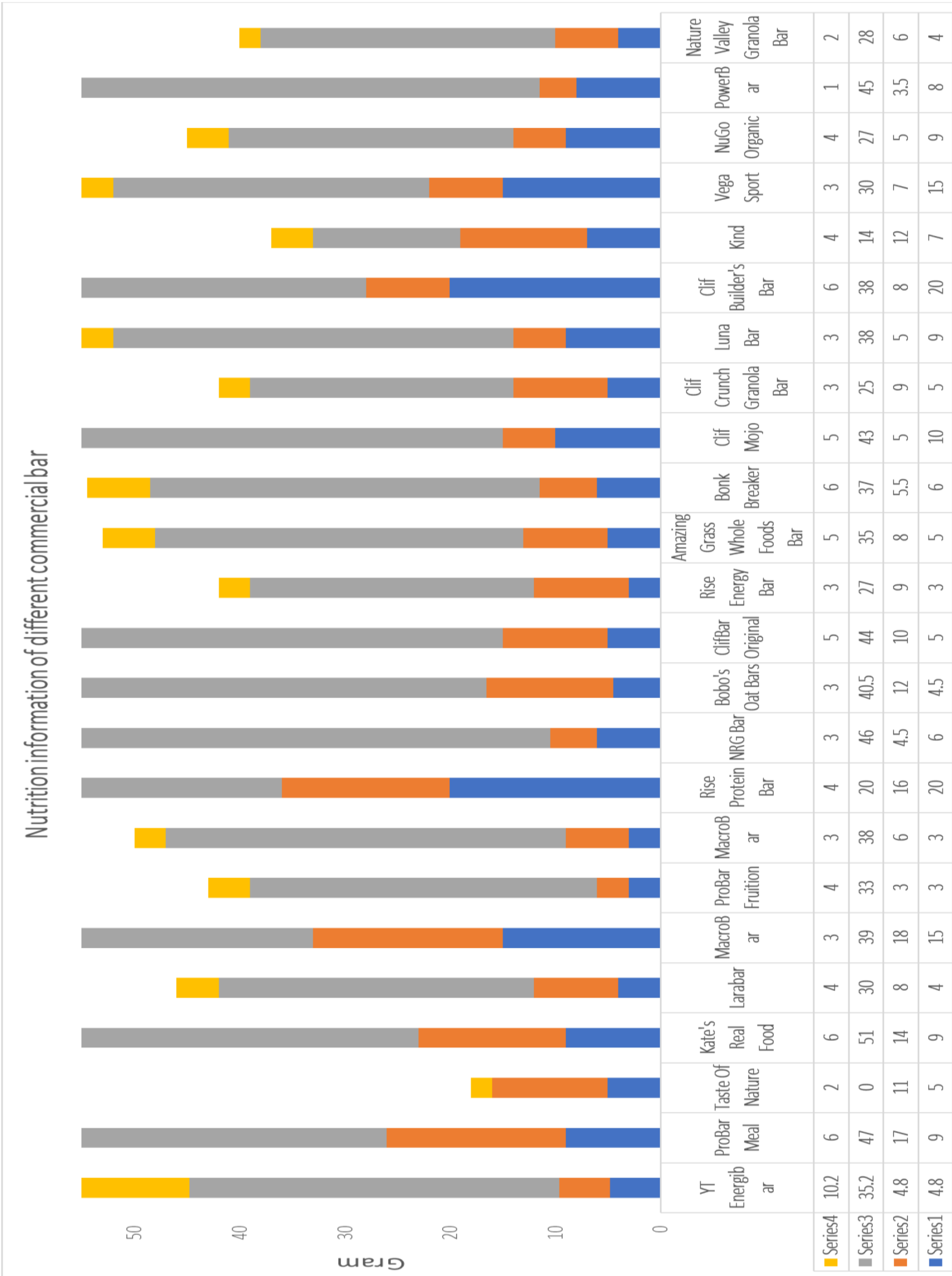


Figure 34. Nutrition content in (g/total serving size of protein, fat, carbohydrate and fiber) in different commercial bars included in the literature review.

3.2. Pre-experiment

Based on the information about nutrient contents and ingredients used in the commercial bars included in the literature review, five different recipes were formulated. Figure 33 shows the calculated energy content of these five different bar formulations of the pre-experiments. The results showed that the formulations varied in energy from approximately 180 Kcal to 210 kcal per serving size of 60 g.

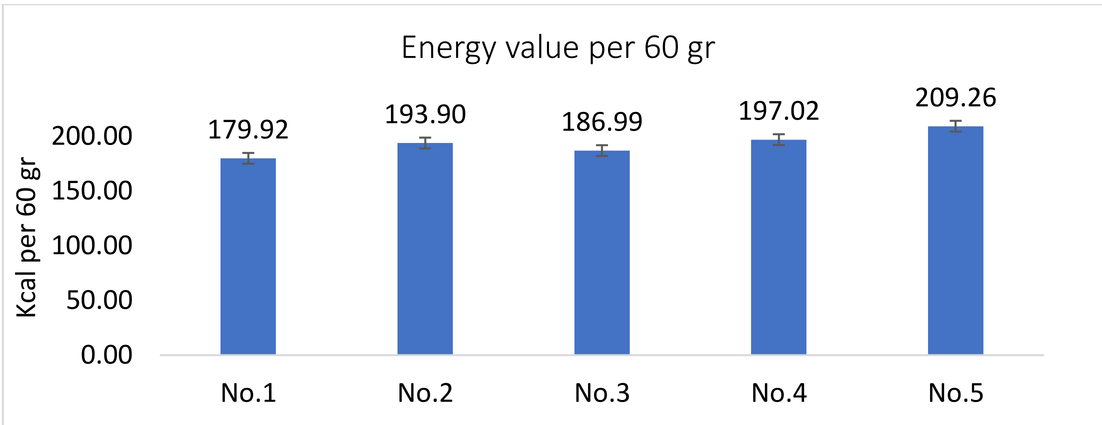
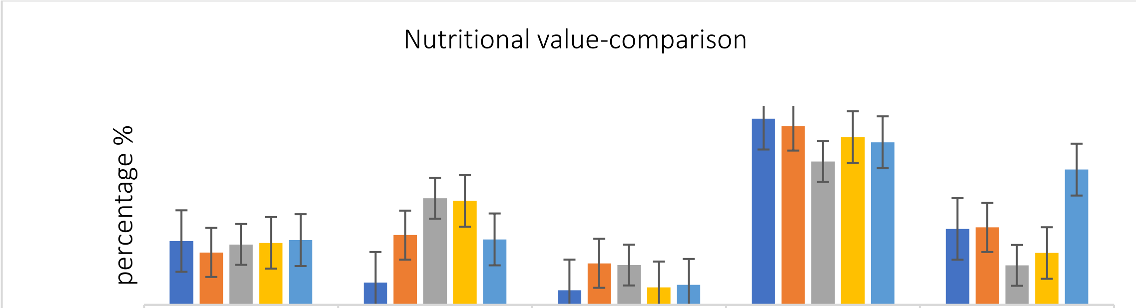


Figure 35. Energy content per 60 gr serving size of the five different recipes

Figure 36 shows the %-distribution of fat, starch, dietary fiber, protein and sugar in the five different formulations in the pre-experiment. The results showed that the fat content was equal among all the formulations, approximately 10%. Both the type and the amount of fat was kept almost the same. The starch content varied between 3.8 and 18.7%. The sources of starches were pumpkin, oat, sweet potato and quinoa. Dietary fiber content also ranged between approximately 2.5 % to 8 %. The protein content varied between approximately 25.5 to 33 %, with main sources from whey proteins, cottage cheese, quinoa and oat. The sugar content showed more variable results, from 7 % to 24 %, among the different recipes. List of ingredients and the weight distribution has been shown in Table 19 and Table 20.



	fat	starch	Dietary fiber	protein	suger
No.1	11.23	3.89	2.56	32.74	13.36
No.2	9.23	12.27	7.32	31.46	13.62
No.3	10.64	18.75	7.01	25.22	6.95
No.4	10.91	18.28	3.09	29.52	9.12
No.5	11.39	11.52	3.51	28.60	23.80

Figure 36. Nutritional value in % of total content of fat, starch, dietary fiber, protein and sugar of the 5 different recipes

3.3. Main experiment

Two formulations from the pre-experiment were selected for further studies to produce baked bars and extruded bars. The selection was based on high protein content with acceptable sensory taste and two different starch sources. These formulations were No.2 Sweet potato and No. 3 Oat. The protein content, 31 % and 25 %, respectively came from whey proteins, cottage cheese and quinoa. Both formulations contained approximately the same energy level (185 and 193 kcal).

3.4.1 Processing parameters of extrusion

The processing parameters and results recorded from the extrusion experiment are presented in Table 24 and Figure 38. Extruded bars with specific properties were produced by changing the screw speed and adding water. The variables resulted in different samples called No.0, No.1, No.2 and No.3, shown in Table 25. The extruder was operated at different screw speed and die diameter 12 mm. The moisture added into the extrusion barrel (Figure 37) was 7-9-11 %, and the highest temperature of 112,6 ºC was observed in section 4. The screw speed and the percentage of added water were the independent variables and the temperature and pressure varied during extrusion. The temperature was lowest in the first section for all samples, then increased during the middle section and decreased in the final section of the extruder (section 5). Extruder screw load, measured in torque, was manually recorded. It was maximum at the beginning of the process and the minimum at the end.

Density of the different extruded bars was calculated after the drying. Due to the poor cohesiveness of the extruded bar No.0, this bar was not analyzed further.

Table 25 Processing parameters of extrusion

sample	UNIT	No.0	No.1	No.2	No.3
Throughput	**Kg/h**	5H	5H	5H	5H
Screw speed	**RPM**	397	321	321	625
Temp. In the extruder					
Section 1	**ºC**	37.6	38.9	38.6	39.3
Section 2	**ºC**	91.4	64.6	73.7	80.1
Section 3	**ºC**	110.4	109.1	102.1	109.5
Section 4	**ºC**	112.6	109.8	107.4	109.2
Section 5	**ºC**	106	107.5	105.9	108.2
Extra. water	**(%)**	7	9	11	11
Density	**g/l**	-	2.21	2.17	2.10
Die Temp.	**ºC**	88	91	93	97
Die pressure	**bar**	2.4	1.8	1.6	1.1
Pressure, section 4	**bar**	0.56	0.23	0.2	0.33
Torque	**Nm**	193	133	124	114
torque relative	**RPM**	44	31	28	26

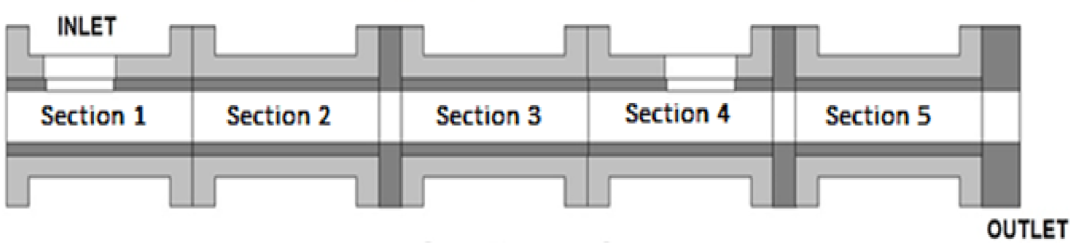
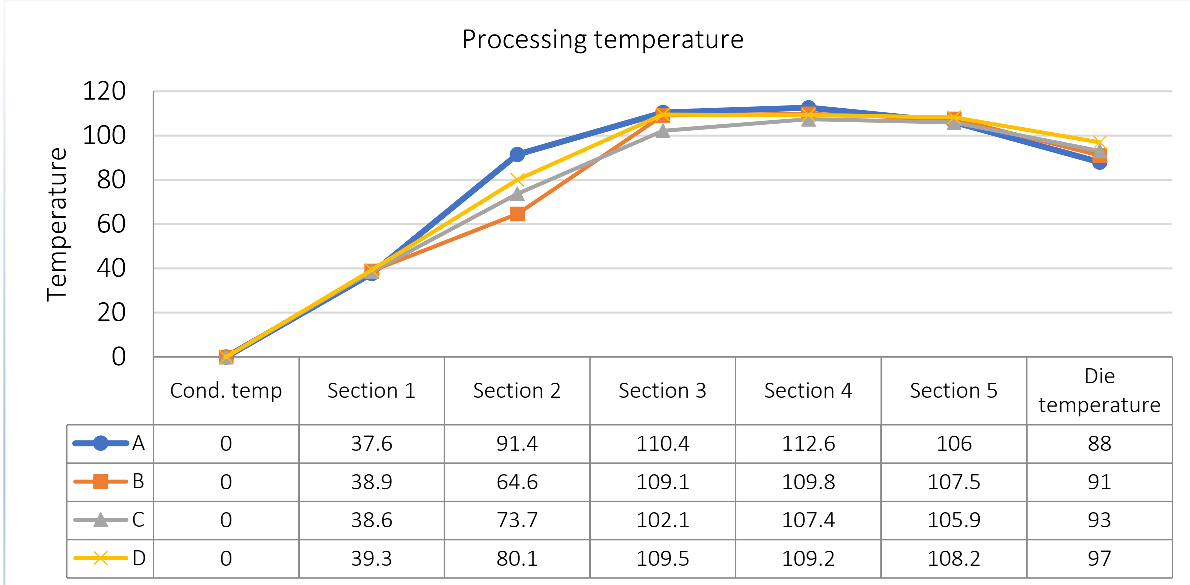


Figure 37. Extrusion barrel sections



	Cond. temp	Section 1	Section 2	Section 3	Section 4	Section 5	Die temperature
A	0	37.6	91.4	110.4	112.6	106	88
B	0	38.9	64.6	109.1	109.8	107.5	91
C	0	38.6	73.7	102.1	107.4	105.9	93
D	0	39.3	80.1	109.5	109.2	108.2	97

Figure 38. Processing temperature in the different sections during extrusion
A: sample No.0 B:sample No.1 C: sample No.2 D:sample No.3

3.4.2 Physical-chemical characteristic of the protein bars

3.4.2.1 Moisture content

3.4.2.1.1. Moisture content of Extruded bars

The moisture contents of the four different extruded bars were analyzed and the results are shown in Table 26. The results showed that the moisture content was high, between 24-26 % immediately after extrusion therefore these extruded bars were dried further for one day to reach the standard moisture content of storage (15-17 %). The drying process continued to keep the moisture content low, 16t % to 16.27 %. The results after freezing (immediately after extrusion) and without any further drying indicated that the drying process after freezing, resulted in a significantly reduction of moisture content of extruded product (Table 26).

Table 26. Moisture content of the extruded samples measured immediately after extrusion, after freezing and after drying

Samples No.	Screw speed	Added water	After extrusion	After freezing	After drying
No.0	397	7 %	20.05	-	-
No.1	321	9 %	24.31	24.23	16
No.2	321	11 %	25.84	24.92	16.22
No.3	625	11 %	26.26	25.67	16.27

3.4.2.1.2 Moisture content of baked bars

The moisture content of the baked protein bars was analyzed. The baked bar at the lowest temperature 50 ^{0}C baked for 15 min showed the lowest moisture content (Table 27, Figure 39).

Table 27 % Moisture content of baked bar

Time inside oven	Temperature	Moisture content (%) After drying
5 min baking +10 minutes drying(A)	100	19.73
15 min baking +5 minutes drying(B)	50	18.15

Figure 39. Protein baked bar

3.2.2.2 Water activity

3.2.2.2.1 Water activity of extruded bars

The water activity of extruded bars after drying were in the range 0.587 to 0.656 as shown in Table 28, which was acceptable for storage (0.58-0.9).

Table 28. Water activity of extruded bars after drying

Sample No.	Screw speed	Added water	W_a	Temp
No.1	397	7%	0.587	25.87
No.2	321	9%	0.625	25.52
No.3	321	11%	0.656	25.47

3.3.2.2.2 Water activity of baked bars

The result of water activity measurements of the baked bars was in the range, 0.61 - 0.66 as shown in Table 29.

Table 29. Water activity of baked bars

Time inside oven	Temperature	Moisture content	Aw	Temperature
5 min baking+10 minutes drying(A)	100^{0} C	19.73 %	0.614	24.06
15 min baking +5 minutes drying(B)	50^{0} C	18.15 %	0.662	25.53

3.3.2.2.3 Hardness of extruded bars

The hardness of the different extruded bars showed that the protein bar No. 3 had the lowest hardness (Table 30, Figure 40) and bar no.1 the highest hardness.

Table 30. Different Extrusion Conditions

Sample No.	Screw speed	Added water	Hardness(kg)
No.1	397	7 %	9.33
No.2	321	9 %	7
No.3	321	11 %	6.08

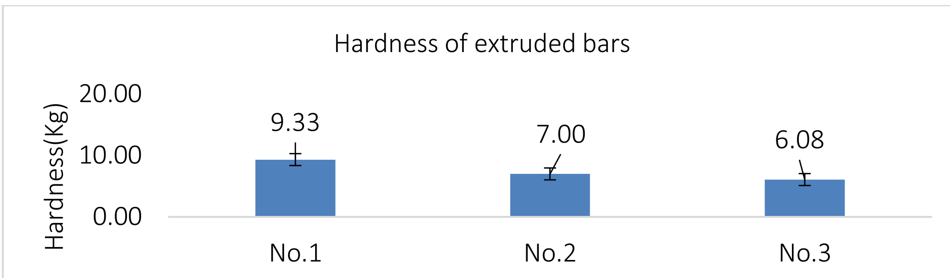


Figure 40. Hardness of the different extruded bars

3.3.2.2.4 Bulk density of the extruded bars

The result of bulk density of the different extruded bars were in the same rage, from 2.10 to 2.21 g/ml as in Figure 41. Bulk density of the extruded bar Figure 41.

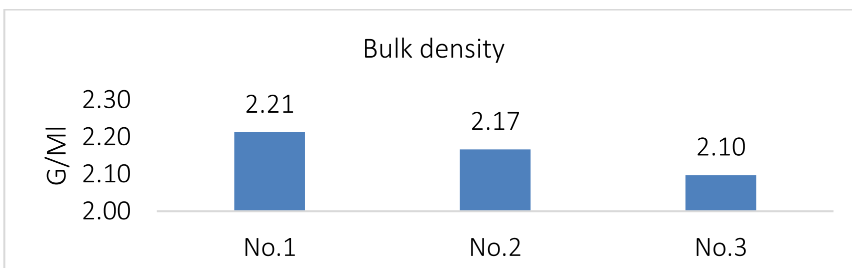


Figure 41. Bulk density of the extruded bars

3.3.2.5. Expansion ratio of the extruded bar

The expansion ratio of the extruded bars showed good expansion for bar No.3 and poor expansion of bar No.1 (Figure 42 and Figure 43).,

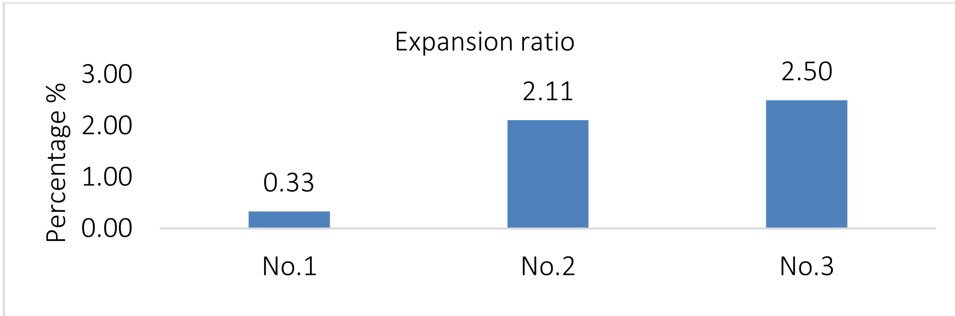
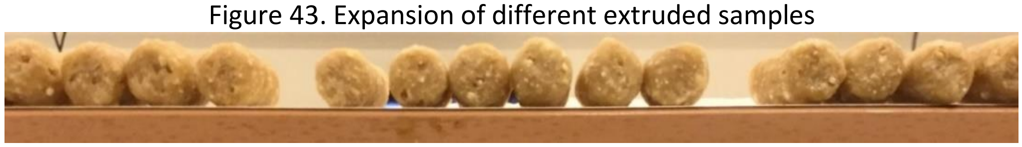


Figure 42. Expansion ratio of the extruded bar

Figure 43. Expansion of different extruded samples



3.5. Nutritional value

3.5.1 Nutritional value of the extruded bars.

The nutritional value as energy (Kcal/60g), % of fat, starch, sugar, dietary fiber, protein and dry matter of the extruded bars are shown in the Table 31. The data is calculated according to the USDA's National Nutrient Database, information from the manufacturer and literature and MATVARETABELLEN.

Table 31. Nutritional content of produced extruded bar

	Gr	kcal	% Fat	% Starch	% Sugar	% Dietary fiber	% Protein	% Dry Matter
Extruded bar	60	217	10.6	15.44	16.45	3.24	37.84	**83.59**

Figure 44 shows the percentage distribution of the different proteins used in extruded protein bars. The highest protein contribution was whey proteins (33%), then quinoa (2%) and oat flakes (1.5%), whereas cottage cheese accounted for 0.32%.

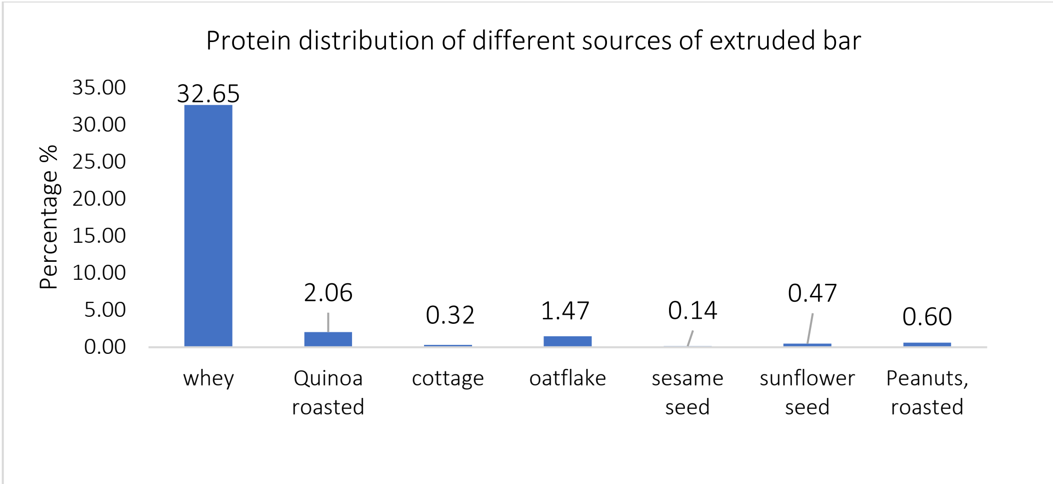


Figure 44. Protein distribution of different ingredients in the extruded bars

Figure 45 displays the concentration of different starch sources in the extruded bars. It shows that the main starch content was quinoa with approximately. 8% and oat flakes 7%.

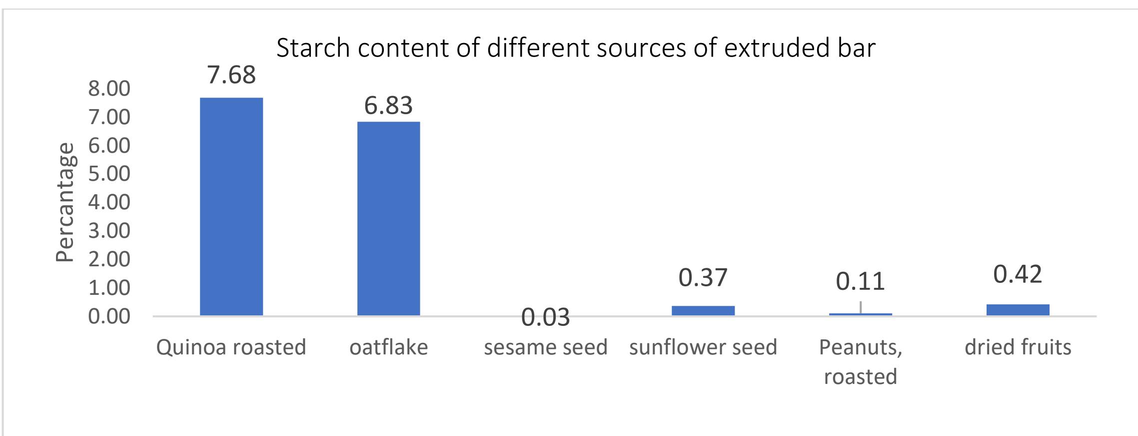


Figure 45. Starch content of the different sources in the extruded bars

3.5.2 Nutritional value of the baked bars

The nutritional value of baked bars is displayed in the **Error! Not a valid bookmark self-reference.**The baked bars had an energy of 210 kcal/60g, the protein content was appr.30%, starch 13%, fat 11%, sugar 16% and dietary fiber 3%. The values were calculated based on the data that has obtained from the USDA's National Nutrient Database and information from the manufacturer and literature. Nutritional value of the extruded bars.

The nutritional value as energy (Kcal/60g), % of fat, starch, sugar, dietary fiber, protein and dry matter of the extruded bars are shown in the Table 31. The data is calculated according to the USDA's National Nutrient Database, information from the manufacturer and literature and MATVARETABELLEN.

Table 32. The nutritional value of the baked bars

	Gr	Kcal	% Fat	% Starch	% Sugar	% Dietary fiber	% Protein	% Dry matter
Baked bar	60	210.67	11.64	13.41	16.18	2.73	29.08	**76.66**

Figure 46 displays the percentage of protein sources in the baked bars, with whey protein as the highest protein content appr.23%, quinoa 3% and cottage cheese 1.2%.

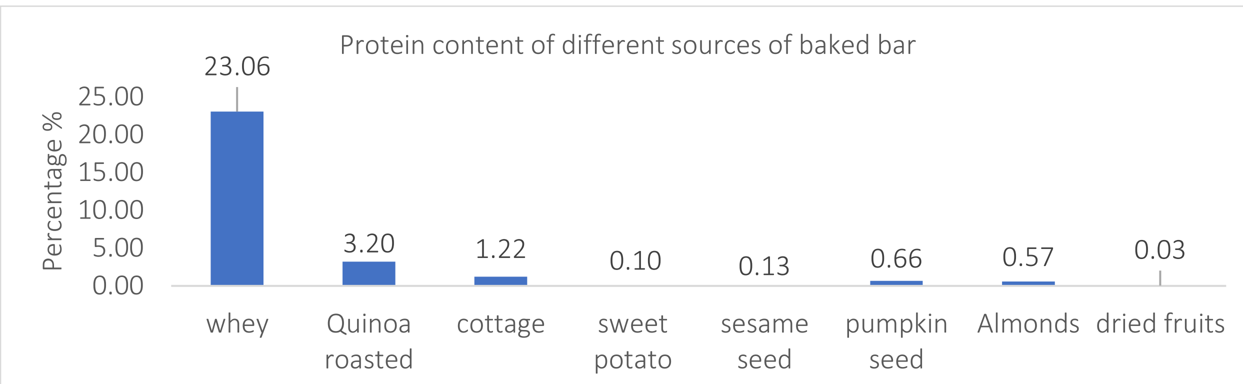


Figure 46. Protein content of different sources in the Baked bar

Figure 47 shows the various starch sources that has been applied in the baked bars. It is clear that starch from quinoa (12%) was the dominating the starch source and less than 1% from sweet potatos, pumpkin seeds an dried fruit.

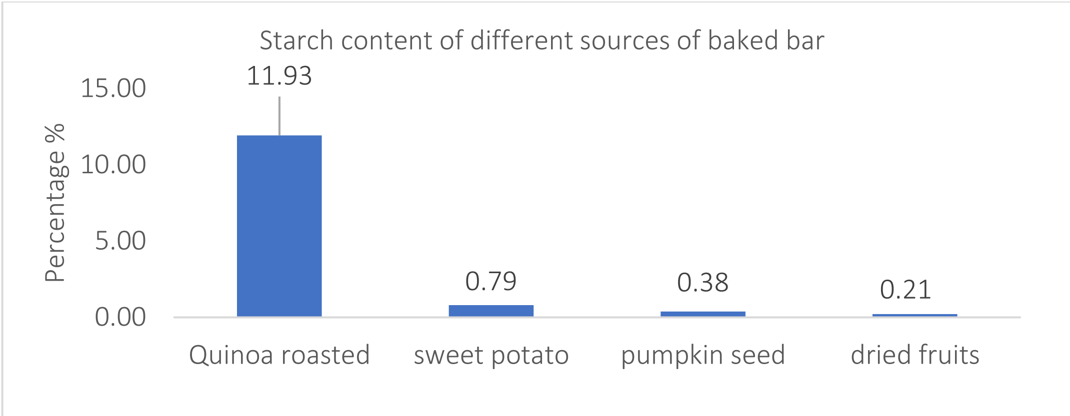


Figure 47. Starch content of different sources of the baked bars

3.6 Sensory evaluation

Sensory evaluation of extruded bars and baked bars were analyzed for appearance, taste, smell and texture in comparison with two commercial bars. The commercial bars were selected for their high protein content. The panel consisting of 8 persons, ranking the four different protein bars with a score from 1 to 4. Best score was 4 and in a descending order 3, 2 and 1 (lowest score) for each single characteristic. The characteristics (attributes) were appearance/color, taste/flavor, smell/odor and texture/mouthfeel according to Fig 25. A statistical data program, similar to qualitative descriptive analysis (QDA) was used to evaluate differences among the protein bars.

3.6.1 Statistic

The results of the mean score of the overall acceptance of the different attributes (appearance, taste, smell, texture) are summarized for all of the four bars, extruded and baked bars, and the two commercial bars, PROTEINBAR chocolate bar and Quest bar in the Figure5 (Appendix).The results of the descriptive statistical data analysis are shown in Table 33. It shows maximum and minimum score for each sample, where 4= the most like and 1= the dislike.

Table 33. Descriptive statistics of summarized data

	Overall acceptance of appearance			Overall acceptance of taste			Overall acceptance of smell			Overall acceptance of texture		
	N=No. of participants	Min	Max	N=No. of participants	Min	Max	N=No. of participants	Min	Max	N=No. of participants	Min	Max
Extruded bar	8	1	2	8	1	2	8	1	3	8	1	3

Baked bar	8	1	4	8	1	3	8	1	4	8	1	4
Chocolate bar	8	1	4	8	2	4	8	1	4	8	2	4
Quest bar	8	2	4	8	1	4	8	1	3	8	1	4

However, the descriptive statistical data analysis could not make any discrimination between the bars. It simply describes our data [72] and this means that we cannot find which bar were more acceptable than the others.

3.6.1.1 Multiple comparisons (post hoc results)

Post hoc analysis includes checking the data, after the experiment has finalized, for patterns that were not specified beforehand. The Multiple Comparisons, displays which groups varied from each other. The overall results of the four bars related to appearance, taste, smell and texture are summarized in the following tables (Table 34-38).

Table 34. Multiple comparisons of the four bars related to overall appearance

Dependent Variable: overall appereance

Tukey HSD

(I) protein food bar	(J) protein food bar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Extruded	Oven Backed	-1.250*	.429	.033	-2.42	-.08
	chocolate bar	-1.500*	.429	.008	-2.67	-.33
	Quest bar	-2.125*	.429	.000	-3.30	-.95
Oven Backed	Extruded	1.250*	.429	.033	.08	2.42
	chocolate bar	-.250	.429	.937	-1.42	.92
	Quest bar	-.875	.429	.198	-2.05	.30
chocolate bar	Extruded	1.500*	.429	.008	.33	2.67
	Oven Backed	.250	.429	.937	-.92	1.42
	Quest bar	-.625	.429	.476	-1.80	.55
Quest bar	Extruded	2.125*	.429	.000	.95	3.30
	Oven Backed	.875	.429	.198	-.30	2.05
	chocolate bar	.625	.429	.476	-.55	1.80

*. The mean difference is significant at the 0.05 level.

Table 34 in overall appearance of the four bars showed that a significant difference was found in the overall acceptance between the extruded bar and the commercial Quest bar. No significant difference was found in the overall acceptance between the backed bar and the two commercial bars; PROTEINBAR chocolate and Quest bar (As the p-value is higher than 0.05). The extruded bar is significant different than the backed bar, the PROTEINBAR chocolate and the Quest bar at 5% level of significance (significant at p-value 0.05). But the remaining protein bars are not significantly different from each other. Moreover, based on the confidence interval, if zero is included in 95% confidence interval, the different bar is not significantly different.

Table 35. Multiple comparisons of the four bars related to overall taste

Dependent Variable: overall acceptance of taste

Tukey HSD

(I) protein food bar	(J) protein food bar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Extruded	Oven Backed	-.625	.446	.508	-1.84	.59
	chocolate bar	-1.750*	.446	.003	-2.97	-.53
	Quest bar	-.375	.446	.834	-1.59	.84
Oven Backed	Extruded	.625	.446	.508	-.59	1.84
	chocolate bar	-1.125	.446	.078	-2.34	.09
	Quest bar	.250	.446	.943	-.97	1.47
chocolate bar	Extruded	1.750*	.446	.003	.53	2.97
	Oven Backed	1.125	.446	.078	-.09	2.34
	Quest bar	1.375*	.446	.022	.16	2.59
Quest bar	Extruded	.375	.446	.834	-.84	1.59
	Oven Backed	-.250	.446	.943	-1.47	.97
	chocolate bar	-1.375*	.446	.022	-2.59	-.16

*. The mean difference is significant at the 0.05 level.

Table 34 in overall appearance of the four bars showed that a significant difference was found in the overall acceptance between the extruded bar and the commercial Quest bar. No significant difference was found in the overall acceptance between the backed bar and the two commercial bars; PROTEINBAR chocolate and Quest bar (As the p-value is higher than 0.05). The extruded bar is significant different than the backed bar, the PROTEINBAR chocolate and the Quest bar at 5% level of significance (significant at p-value 0.05). But the remaining protein bars are not significantly different from each other. Moreover, based on the confidence interval, if zero is included in 95% confidence interval, the different bar is not significantly different.

Table 35 showed that significant differences were found in the overall acceptance of taste between the extruded bar and the commercial PROTEINBAR chocolate (p-value is less than 0.05). No significant difference was found in the overall acceptance of the taste between the backed bar and the commercial PROTEINBAR chocolate bar and Quest bar (p-value higher than 0.05).

Table 36. Multiple comparisons of the four bars related to overall smell

Dependent Variable: overall acceptance of smell

Tukey HSD

(I) protein food bar	(J) protein food bar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Extruded	Oven Backed	-1.875*	.462	.002	-3.14	-.61
	chocolate bar	-1.000	.462	.158	-2.26	.26
	Quest bar	-.500	.462	.703	-1.76	.76
Oven Backed	Extruded	1.875*	.462	.002	.61	3.14
	chocolate bar	.875	.462	.253	-.39	2.14
	Quest bar	1.375*	.462	.029	.11	2.64
chocolate bar	Extruded	1.000	.462	.158	-.26	2.26
	Oven Backed	-.875	.462	.253	-2.14	.39
	Quest bar	.500	.462	.703	-.76	1.76
Quest bar	Extruded	.500	.462	.703	-.76	1.76
	Oven Backed	-1.375*	.462	.029	-2.64	-.11
	chocolate bar	-.500	.462	.703	-1.76	.76

*. The mean difference is significant at the 0.05 level.

The results in Table 36 showed significant difference in the overall acceptance of the smell between the extruded bar and backed bar (p-value is less than 0.05). No significant difference was found in the overall acceptance between the extruded bar and the PROTEINBAR chocolate and the Quest bar (p-value higher than 0.05).

Table 37. Multiple comparisons of the four bars related to overall texture

Dependent Variable: overall acceptance of texture
Tukey HSD

(I) protein food bar	(J) protein food bar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Extruded	Oven Backed	-1.375	.506	.051	-2.76	.01
	chocolate bar	-1.250	.506	.087	-2.63	.13
	Quest bar	-.750	.506	.460	-2.13	.63
Oven Backed	Extruded	1.375	.506	.051	-.01	2.76
	chocolate bar	.125	.506	.995	-1.26	1.51
	Quest bar	.625	.506	.610	-.76	2.01
chocolate bar	Extruded	1.250	.506	.087	-.13	2.63
	Oven Backed	-.125	.506	.995	-1.51	1.26
	Quest bar	.500	.506	.757	-.88	1.88
Quest bar	Extruded	.750	.506	.460	-.63	2.13
	Oven Backed	-.625	.506	.610	-2.01	.76
	chocolate bar	-.500	.506	.757	-1.88	.88

The results in The results in Table 36 showed significant difference in the overall acceptance of the smell between the extruded bar and backed bar (p-value is less than 0.05). No significant difference was found in the overall acceptance between the extruded bar and the PROTEINBAR chocolate and the Quest bar (p-value higher than 0.05).

Table 37 showed no significant difference in the overall acceptance of texture between the bars (p-value higher than 0.05).

3.6.1.2 Tukey Test / Honest Significant Difference

Tukey's multiple comparison tests are one of various tests that it used to specify which mean(average) value between a set of means vary from the rest.

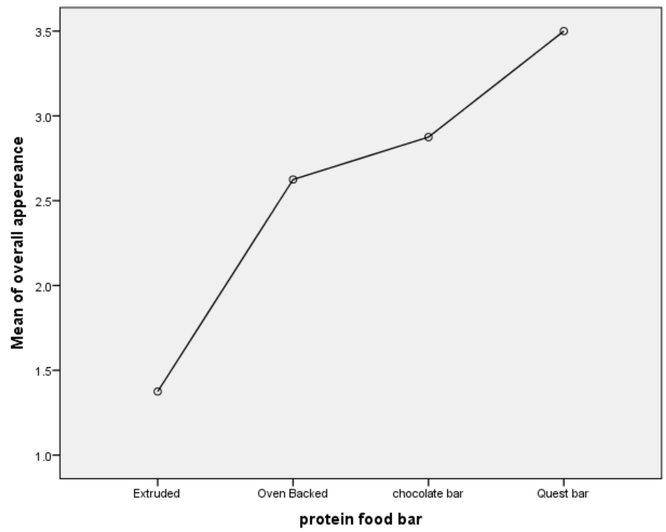


Figure 48. Mean value of overall acceptancy of appearance

The results of mean of overall acceptancy of appearance of the four bars (Figure 48) showed that no significant difference was found in the overall acceptance between the backed bar and the two commercial bars. The panelist preferred appearance of the Quest bar over the other protein bars due to score of Quest bar, which according to 4-point hedonic scale (where 4= the most like and 1= the most dislike) the panelist like Quest bar moderately.

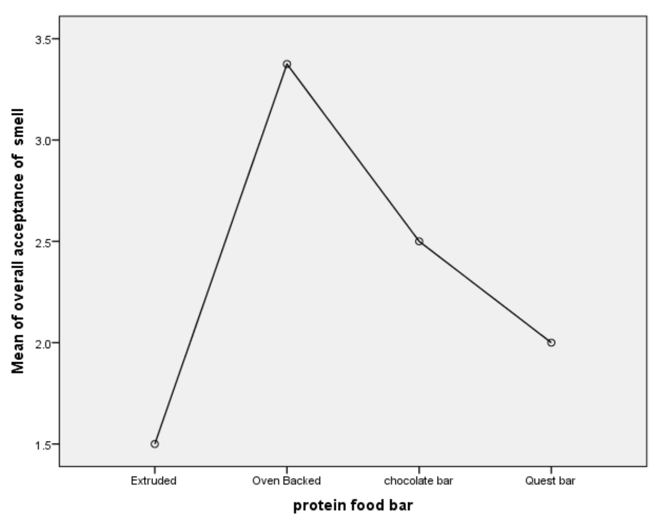


Figure 49. Mean of overall acceptancy of smell

The results from of overall acceptancy of smell of the four bars (Figure 49) showed that the panelist preferred smell of the backed bar over the other protein bars, due to score of the backed bar which according to hedonic scale the panelist like it moderately.

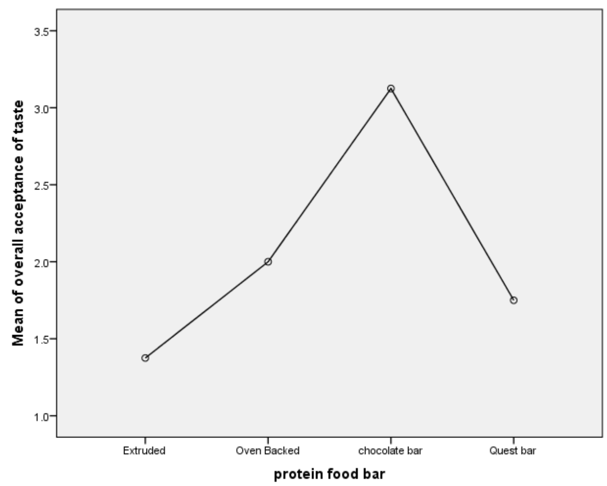


Figure 50. Mean of overall acceptancy of taste

The results of overall acceptancy of taste of the four bars (Figure 50) the backed bar and the PROTEINBAR chocolate bar differed significantly in the overall taste acceptance, however, no significant difference in the overall taste acceptance between the backed bar and the commercial bars were found. The panelist preferred taste of the commercial chocolate bar over the other protein bars due to score of the PROTEINBAR chocolate bar, which according to 4-point hedonic scale (where 4= the most like and 1= the most dislike). The panelist like the PROTEINBAR chocolate bar moderately.

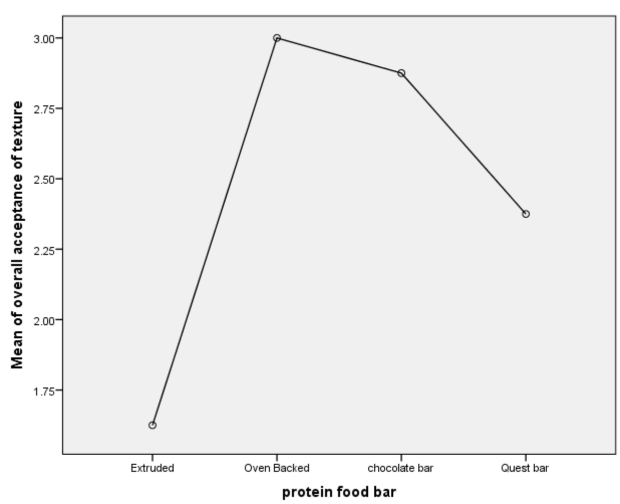


Figure 51. Mean of overall acceptancy of texture

The results from of overall acceptancy of texture of the four bars (Figure 49) indicated that the panelist preferred texture of the backed bar over all the other protein bars, due to score of the backed bar, which according to the hedonic scale the panelist like it moderately.

3.6.2 Sensory evaluation related to consumer acceptability

Some questions presented in Figure 32 on consumer acceptability were responded by 20 students. The participant's age was between 18-25 years old. 84.2 percentage were women and 15.8% were men. Analysis of frequency in purchasing and consumption of a "snack food bar" showed that less than 11% of the participants bought a snack bar once a week and 37 % of the participants consumed such bars once a month. More than 50 % of the participants bought snack bars very seldom, only two or less times per year.

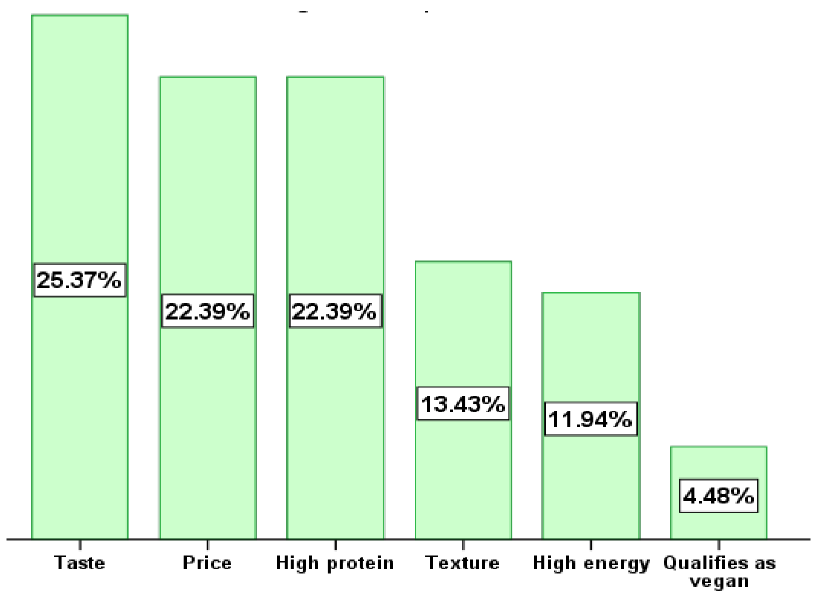


Figure 52. Priority in choosing the protein bar

This survey indicated that taste is the first priority with 26 % of total and the price (23%) and high protein content (23%) are the next specifications when consumers consider making a purchase decision for bars, as shown in Figure 52 .This continued with texture (13.5 %) and high energy bar by 12 % and less than 5 % for vegan.

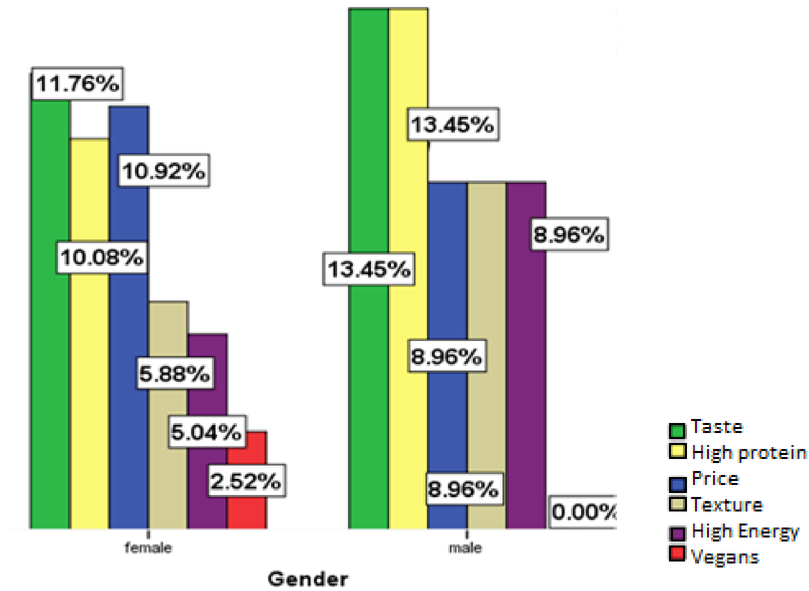


Figure 53. The difference in snack foods consumption between males and females

The results indicated differences between males and females for the type of snack foods consumed. However, the second choice for females were high energy bars and for men high protein bars, price seems to be as the exclusive cause for both gender Figure 53.

Regarding to how consumers typically choose a food bar or protein bar, it was observed that around 79% of all participants actually read product labels when buying snack foods, most of the consumers considered their diet to be healthy and wants to know the nutritional quality of snack before buying it Table 38.

Table 38. How consumers typically choose a food bar or protein bar

	%Q1*	%Q2*	%Q3*	% Q4*	% Q5*	%Q6 *	% Q7*
Agree	94.7	89.5	57.9	52.6	89.5	21.1	42.1
Neither nor	5.3	5.3	42.1	36.8	10.5	0	42.1
Disagree	0	5.3	0	10.5	0	78.9	15.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Q1: A healthy diet is very important to me. Q2: I want to know the nutritional quality of snack before buying it Q3: I would choose snacks fortified with protein. Q4: I would choose snacks with less fat. Q5: I would choose snacks containing less trans-fat Q6: I never pay attention to the list of ingredients of snacks before buying it. Q7: I would encourage my kid(s) to consume snacks fortified with protein rather than regular snack.

The results (Figure 54) showed that the baked bars were more acceptable by more than 90 % percent of the customers.

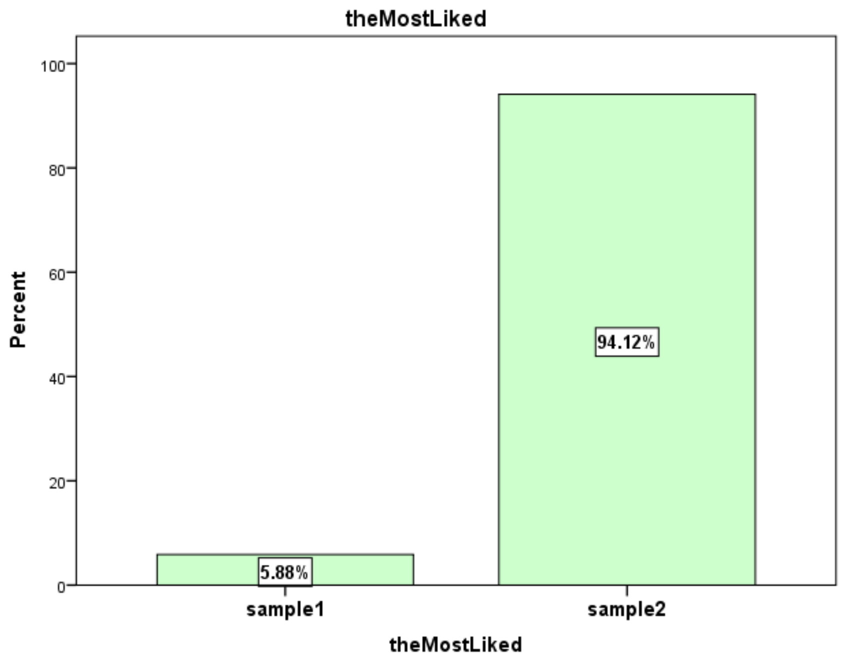


Figure 54. %-of the most liked bars, sample 1 extruded bars, sample 2 baked bars

4 Discussion

This study aimed to produce a high protein bar with more than 30 % protein by two processing methods; extrusion and conventional baking, and to compare the sensory properties of these with existing low protein bars (20%) on the market. A literature study of commercial bars and their composition was done before selecting the different ingredients to be used in the recipes for the five bars in the pre-experiment and for the two bars in the main experiment.,

In total, 24 commercial bars were included in the literature study. Most commercial bars on the market have high energy content based on carbohydrate, fat and low in protein (<20%) for serving size (40-60 g). More to be included here to be discussed about the ingredients of the commercial bars (literature study).

The commercial bars with highest protein contents were to Cliff builders bar and Rise protein bar both containing 20 g protein per serving (40-60 g). The rest of the commercial bars contained lower amounts of protein, most of them less than 10 g per serving. These bars are mostly used as energy bars since the amount of carbohydrate are very high, all in the range of 20-50 g. The highest energy content Kate's Real Food bar and Tine YT bar had the highest energy content with approximately 360 kcal per 100 g, hence, these should be considered as meal replacements (up to 250 kcal per 100 gram) rather than snacks. Very few of the commercial bars had an acceptable taste, simply by serving them to a limited number of people at the Food science group without any further sensory evaluation. The protein ingredients; whey protein concentrate (WPC80), cottage cheese and quinoa, used in the pre- and main experiments in this study were selected based on their high nutritional value. Both whey proteins and caseins have high biological value due to the amino acid composition. Besides, whey is a byproduct from cheese production, and the industry would like to find alternative products for the use of these nutritional proteins. The functional properties of whey proteins are also very good with high solubility and good gel forming properties. In addition, quinoa was selected as a protein source due to a relatively high protein content (16 %). Moreover, quinoa has a high content of the essential amino acids methionine and phenylalanine, which are low in milk proteins. The other ingredients selected in this pre-experiment were carbohydrate (starch), fat and natural sweetener. The starch content is very important and not be lower than 10% in for obtaining good swelling and gelatinization of the mixture during extrusion. The sweet potatoes, quinoa and oat flakes were selected with starch contents varying from 3-18%. The sweet potatoes are different in taste, size, shape and texture. They are rich in vitamin A and many other nutrients like dietary fiber, and minerals including potassium, copper and iron[87]. Starch is the main constituent of sweet potato roots, consisting of 50% to 80% of the dry matter. It has lower swelling and solubility ability at temperatures around 60 to 90 °C compared with potato and cassava starches[88]. Sweet potatoes are one of the vegetables with a medium GI range in In comparison to potatoes and cassava [89]. Oat has many unique properties compared to other cereals some of them include high content of water soluble fiber, with several dietary benefits[90].Further the amount of starch, type of starch and ratio of amylose to amylopectin are also important factors in selecting the starch source.

The fat ingredients were selected based on their content of unsaturated fatty acids. Vegetable oils and nuts were chosen to avoid saturated fat and supply the bars with omega-6 fatty acids in sunflower oil and nuts (Figure 56 Appendix). A fat content of approximate 10 % was selected. For products to be extruded, fat should not exceed 20 % as a higher fat content has may have negative impact on the final product characteristics such as expansion rate [91]. Besides, fat has a high-energy content compared to proteins and carbohydrates., and the energy from fat should be kept low in our high protein bars.

Different natural low calorie sweeteners were selected to keep energy and sugar content low. Stevia is around 30 times sweeter than sugar, in addition stevia and sukri are type of sweetener that the humans does not metabolize them [92].

The ingredients selected for the main experiment was based on the result of the pre-experiments. It was really important to have the good sensory taste and texture, and also at the same time a proper crunchiness [73]. A critical factor in extrusion is the formulation of the ingredients, to ensure a proper balance between water, starch, fat, proteins and the other ingredients, as this may affect the processing. In high protein recipes, the ratio of wet and dry ingredients must be considered to get a homogeneous mixture suitable for the extrusion process. To prevent creating lumps in the mixture is a challenge when blending dry and wet materials with different viscosities [74].

When extruder technique is applied, several process and system variables and their impact on the physical quality of the products are reported to be a challenge [93]. Changing one variable does not indicate clearly the influence on another parameter. The food ingredients and specially starches and proteins display various behaviors in the presence of water and heat. Solubilization, gelatinization and denaturation alter the structure and interactions of the different compounds in the matrix [93]. During extrusion, operational factors like screw speed play a significant role in the product quality and factors such as adding moisture to the blend also affects the quality of extrudate [73]. In this study, several factors with impact on the quality of extrudate were studied. Our results showed that high screw speed and high moisture content (11 %) were shown gave the best radial expansion and a softer texture. Increasing specific mechanical energy (SME) has been reported to result in higher melting temperature, higher steam flash-off and expansion of the extrudate at the die[76]. An increase in screw speed also cause a better moisture distribution[76] . Samples with the same screw speed, but lower amount of water added gave a more tough texture. The mixture with 7% added water and low screw speed did not display a good cohesiveness and was therefore not considered further. Two processing techniques were performed, the extrusion was applied to the oat recipe and baking was used for the Sweet potato recipe. The first was suitable for extrusion process. In the extrusion process, the ingredients were subjected to high temperature, high pressure and short mixing time, less than 30 s. In the baking process, applied to the Sweet potato recipe, products were baked at 50 or 100 °C for 5-10 minutes, Overall the baked bars gained a better texture and appearance and the taste of the baked bar were more acceptable. The extruded bars did not have enough crunchy texture or acceptable taste.

Using glycerol as a binding agent of water helped to keep the moisture content high, around 16-17%, but crunchiness was low.

The die and shape also influenced the texture and hardness of the final product. the round or triangle shapes indicated a harder texture. The baked protein bars were softer and more cohesive than those prepared in the extruder. Although, it is not possible to compare them, since the two types contained different ingredients.

5 Conclusion

Two different high protein bars were produced using extrusion and baking technology. The protein content of the extruded bars was appr.38% and consisted of whey proteins (32%), cottage cheese (0.3%) and quinoa (2%). The baked bars had a protein content of appr.30% of whey protein (23%), cottage cheese (1.2%) and quinoa (3%). The extruded bars with the highest moisture content (11 %) showed the best radial expansion and a softer texture. The extruded bars had a desirable low water activity (aw=0.6) and therefore good storage capacity. Parallel with the extrusion, the baking technology was applied to create high protein bar with soft texture. Two different temperatures backing time was used. The bars with the lowest temperature (500C) and the longest baking time gave the best texture.

The sensory analysis, taste, texture, smell and appearance of the extruded and baked bars were evaluated and compared with two commercial protein bars on the market. The results showed that the baked bars obtained the best score for two properties, texture and taste, compared to the extruded bars that achieved the lowest rank of all the bars.

This means that the ingredients and formulation used for producing protein bars with the extrusion technology need to be modified to improve the final consumer's demand.

6 Future aspects

Based on this study, future work in this field should aim at improving texture and sensory properties of high protein bars. Different strategies should be applied depending on the production method:

1. Regarding extruded protein bars the following modifications can be tested:
   - Modification of the recipe:
     1- Change of type of fat and fat source, using nuts instead of oil and liquid fat
     2- Increase starch concentration to get more crunchiness (more than 15%), and also choosing starch with high expansion properties
     3- Substitute parts of the whey protein concentrate with proteins from other sources or using hydrolyzed protein to avoid dryness and improve texture avoid the use of glycerol as a humectant to prevent chewiness and obtain better texture
     4- Reduce the degree of mixing of ingredients prior to extrusion (less mixing more texture acceptability)

- Modification of the extrusion process
  - Change screw configuration with mild aggregation (to avoid extra mixing)
  - Modify of shape and size of the extruded products, by changing the die size and shape

- Regarding baked protein bars the following modifications can be tested:
  a. Modification of the recipe:
     - Avoid the use of glycerol as a humectant to prevent chewiness and obtain better texture
     - Changing the starch content to have more crunchiness
     - Chocolate coating to improve taste and texture

- Modification of the baking process
- Increase temperature to get more expansion or starch gelatinization
- For both recipes:
  - o Add some vitamins and nutrients to Make a special supplementing a diet

7 Appendix

Table 39 . Differen comerical bars and their total ingredients

Product name	Category	INGREDIENTS
Taste of Nature	**Snack**	almonds, raisins, sesame seeds, agave nectar, sunflower seeds, brown rice syrup, pumpkin seeds, whole grain brown rice crisps.
Kate's Real Food	**Meal Repl.**	**INGREDIENTS:** Organic **oats**, Organic honey, Organic peanut butter (organically grown dry roasted peanuts, salt), Organic dark chocolate (organic evaporated cane juice sugar, organic chocolate liquor, organic cocoa butter, organic soy lecithin, organic vanilla), rice nuggets (rice flour, rice bran, raisin juice concentrate, honey, salt), Organic flax seeds, Organic hemp seeds, sea salt.
MacroBar	**Meal Repl.**	Organic Brown Rice Syrup, Organic Gluten-Free Rolled **Oats**, Organic Raisins, Organic Almond Butter, Organic Walnuts, Organic Unsweetened Coconut, Organic Dates, Organic Puffed Brown Rice. Manufactured in a facility that processes peanuts and other nuts. May contain pit or nutshell fragments.
MacroBar	**Snack**	Organic Brown Rice Syrup, Organic Almond Butter, Organic Protein Blend (Organic Sprouted Brown Rice Protein, Organic **Pea Protein**), Organic Bananas, Organic Puffed Brown Rice, Organic Sunflower Seeds, Organic Walnuts, Organic Coconut Sugar, Organic Cinnamon, Organic Natural Banana Flavor. Manufactured in a facility that processes peanuts and other nuts. May contain pit or nutshell fragments.
Rise Protein Bar	**Meal Repl.**	3 real food ingredients, 20g of protein- Ingredients: Almonds, honey, **whey protein isolate.** non-GMO | Soy-Free | Gluten-Free | Kosher | Grain Free-No Artificial Sweeteners | No sugar alcohols | No Preservatives-12 Count / 2.1oz Bars
Bobo's Oat Bars	**Meal Repl.**	**ingredients:** organic rolled oats, brown rice Syrup (brown rice, filtered water), oil blend [palm, canola and olive oils, filtered water, salt, Natural flavor, sunflower lecithin, lactic acid (derived from sugar beets), annatto extract (color)], organic raw sugar, xanthan gum. May Contain Traces of Tree Nuts and Peanuts.
ClifBar Original	**Meal Repl.**	Organic Brown Rice Syrup, **Organic Rolled Oats,** Soy Protein Isolate, Organic Almonds, Rice Flour, Organic Roasted Soybeans, Organic Cane Syrup, Concentrated Apple Puree, Organic Soy Flour, Organic Oat Fiber, Organic Date Paste, Dried Blueberries, Almond Butter, Organic Invert Sugar Syrup, Apple Juice Concentrate, Organic Glucose Syrup, Organic Sunflower Oil, Blueberry Puree, Sea Salt, Natural Flavors, Citric Acid, Barley Malt Extract, Pectin, Elderberry Juice Concentrate (for Color), Lemon Powder, Mixed Tocopherols (Antioxidant). ALLERGEN STATEMENT: CONTAINS SOY AND ALMONDS. MAY CONTAIN TRACES OF PEANUTS, WHEAT, AND OTHER TREE NUTS
Bonk Breaker	**Snack**	Brown Rice Syrup, Peanuts, **Gluten-Free Oats**, Honey, Strawberry Jam [Sugar, Water, Strawberry Puree, Glucose Syrup, Citric Acid, Pectin, Natural Flavor, and Natural Red Radish Pigment (for color)], Rice Flour, Rice Protein, Rice Crisps (Rice Flour, Sugar, Salt, and Calcium Carbonate), Flaxseed Meal, and Sea Salt.
Clif Mojo	**Snack**	Organic Brown Rice Syrup, Organic Peanuts, Soy Rice Crisps (Soy Protein Isolate, Organic Rice Flour, Calcium Carbonate), Peanut Butter–Filled Pretzels (Enriched Wheat Flour [Niacin, Reduced Iron, Thiamin Mononitrate, Riboflavin, Folic Acid], Peanut Butter, Salt, Baking Soda), Peanut Butter Chips (Dried Cane Syrup, Palm Kernel Oil, Peanut Flour, Soy Lecithin), Organic Pretzels (Organic Wheat Flour, Salt, Organic Canola Oil, Organic Malt), Organic Peanut Butter, Organic Roasted Soybeans, Organic Oat Syrup Solids, Vegetable Glycerin, Peanut Flour, Organic Sunflower Oil, Roasted Peanut Extract, Sea Salt, Organic Gum Arabic, Natural Vitamin E (Antioxidant). ALLERGEN STATEMENT: Contains soy, peanuts, wheat, and traces of milk.

Clif Crunch Granola Bar	**Snack**	Organic Rolled **Oats,** Organic Dried Cane Syrup, Organic Sunflower Oil, Chocolate Chips (Dried Cane Syrup, Unsweetened Chocolate, Cocoa Butter, Soy Lecithin, Vanilla Extract), Rice Crisps (Rice Flour, Barley Malt Extract, Dried Cane Syrup, Salt, Calcium Carbonate), Honey, Natural Flavors, Organic Barley Flakes, Organic Rye Flakes, Oat Bran, Oat Fiber, Sea Salt (Real Salt®), Inulin (Chicory Extract). ALLERGEN STATEMENT: Contains soy. May contain traces of milk, peanuts, wheat, and tree nuts.
Luna Bar	**Snack**	**Soy Protein Isolate,** Organic Cane Syrup, Organic Dried Cane Syrup, Palm Kernel Oil, Vegetable Glycerin, Inulin (Chicory Extract), Cocoa‡, Dried Cane Syrup, Macadamia Nut Butter, Natural Flavors, Whey Protein Concentrate, Unsweetened Chocolate‡, Organic Rice Flour, Salt, Soy Lecithin, Cocoa Butter‡, Organic Alkalized Cocoa, Organic Vanilla Extract, Vanilla Extract. VITAMINS & MINERALS: Calcium Carbonate, Ascorbic Acid (Vit. C), Tocopheryl Acetate (Vit. E), Ferric Orthophosphate (Iron), Beta Carotene (Vit. A), Niacinamide (Vit. B3), Folic Acid (Vit. B9), Cyanocobalamin (Vit. B12), Ergocalciferol (Vit. D2), Thiamine Mononitrate (Vit. B1), Riboflavin (Vit. B2), Pyridoxine Hydrochloride (Vit. B6). ALLERGEN STATEMENT: CONTAINS SOY, MILK, AND MACADAMIA NUTS. MAY CONTAIN TRACES OF OTHER TREE NUTS.
Clif Builder's Bar	**Meal Repl.**	**Soy Protein Isolat**e, Beet Juice Concentrate, Organic Brown Rice Syrup, Organic Dried Cane Syrup, Palm Kernel Oil, Almond Butter, Inulin (Chicory Extract), Cocoa‡, Vegetable Glycerin, Organic Soy Protein Concentrate, Natural Flavors, Organic Roasted Soybeans, Rice Starch, Organic Rice Flour, Alkalized Cocoa‡, Organic Oat Fiber, Organic Sunflower Oil, Soy Lecithin, Sunflower Oil, Tapioca Starch, Cocoa Butter‡, Soy Flour, Sea Salt, Unsweetened Chocolate, Salt, Sodium Bicarbonate, Organic Vanilla Extract. ALLERGEN STATEMENT: CONTAINS SOY AND ALMONDS. MAY CONTAIN TRACES OF MILK, PEANUTS, WHEAT, AND OTHER TREE NUTS.
Kind	**Snack**	Almonds, dark chocolate flavored coating (palm kernel oil, chicory root fiber, sugar, cocoa powder, soy lecithin, natural flavor, salt), peanuts, chicory root fiber, honey, walnuts, glucose syrup, rice flour, unsweetened chocolate, sea salt, soy lecithin, sugar.
Vega Sport	**Snack**	Complete protein blend (organic sprouted whole grain brown rice protein, **pea protein**), organic tapioca syrup, organic brown rice syrup, organic cane sugar, organic dates, palm kernel oil, cocoa powder (processed with alkali), unsweetened chocolate, Vega SaviseedTM (sacha inchi) oil, inulin (from chicory root), brown rice crisps, organic agave syrup, peppermint extract, natural vanilla flavor, sunflower lecithin, organic vanilla extract. May contain traces of milk, peanuts, tree nuts, sesame, and soy. May also contain fruit pits.
NuGo Organic	**Snack**	Organic Crunch [organic hexane free **soy** crisps (organic soy protein, organic rice flour, calcium carbonate), organic brown crisp rice, organic rolled **oats]**, Organic Chocolate (organic cane sugar, organic chocolate liquor, organic cocoa butter, organic soy lecithin, organic vanilla), Organic Tapioca Syrup, Organic Agave Syrup, Organic Isolated Soy Protein, Organic Tapioca Maltodextrin, Organic Cocoa Powder, Organic Arabic Gum, Natural Flavors - See more at: http://store.nugonutrition.com/nugo-organic-double-dark-chocolate#sthash.POqGDXhz.dpuf

Descriptives

overall appereance

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Extruded	8	1.38	.518	.183	.94	1.81	1	2
Oven Backed	8	2.63	1.061	.375	1.74	3.51	1	4
chocolate bar	8	2.88	.991	.350	2.05	3.70	1	4
Quest bar	8	3.50	.756	.267	2.87	4.13	2	4
Total	32	2.59	1.132	.200	2.19	3.00	1	4

Descriptives

overall acceptance of taste

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Extruded	8	1.38	.518	.183	.94	1.81	1	2
Oven Backed	8	2.00	1.069	.378	1.11	2.89	1	3
chocolate bar	8	3.13	.835	.295	2.43	3.82	2	4
Quest bar	8	1.75	1.035	.366	.88	2.62	1	4
Total	32	2.06	1.076	.190	1.67	2.45	1	4

Descriptives

overall acceptance of smell

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Extruded	8	1.50	.756	.267	.87	2.13	1	3
Oven Backed	8	3.38	1.061	.375	2.49	4.26	1	4
chocolate bar	8	2.50	1.069	.378	1.61	3.39	1	4
Quest bar	8	2.00	.756	.267	1.37	2.63	1	3
Total	32	2.34	1.125	.199	1.94	2.75	1	4

Descriptives

overall acceptance of texture

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Extruded	8	1.63	.916	.324	.86	2.39	1	3
Oven Backed	8	3.00	.926	.327	2.23	3.77	1	4
chocolate bar	8	2.88	.991	.350	2.05	3.70	2	4
Quest bar	8	2.38	1.188	.420	1.38	3.37	1	4
Total	32	2.47	1.107	.196	2.07	2.87	1	4

Figure 55. The mean score of the overall acceptance

<table>
<tr><th colspan="6">Cold use only (unstable fats, fast oxidation rate)</th></tr>
<tr><th>% SFA</th><th>% MUFA</th><th>% PUFA</th><th>Omega 6 : Omega 3 ratio</th><th>Smoke point (unrefined) [F] / [C]</th><th>Shelf life (months) once opened</th></tr>
<tr><td colspan="6">Sesame Oil
Contains unique antioxidants that are not destroyed by heat. It's a good source of vitamin E and K, high in omega 6, use sparingly after cooking and in salads.</td></tr>
<tr><td>15</td><td>40</td><td>45</td><td>45 : 1</td><td>400 / 200</td><td>2 / 4</td></tr>
<tr><td colspan="6">Fish Oil (average values)
Fish oil should never be used for cooking and should be refrigerated. It's usually consumed in the form of supplement (don't heat). It contains no omega 6 fatty acids! Cod liver oil (best fermented) is very high in vitamin A, E, D and K.</td></tr>
<tr><td>20 / 30</td><td>27 / 57</td><td>15 / 40</td><td>1 : 6 / 1 : 8</td><td>235 / 110</td><td>12</td></tr>
<tr><td colspan="6">Krill Oil
Omega 3s in krill oil are identical to the lipids in the human cell membrane and hence do not need to be converted like they do in case of fish oil. It's usually consumed in the form of supplement. Do NOT heat!</td></tr>
<tr><td>20 / 31</td><td>27 / 58</td><td>15 / 41</td><td>1 : 12</td><td>235 / 110</td><td>12</td></tr>
<tr><td colspan="6">Hazelnut Oil
High in MUFA but also PUFA (omega 6) - use sparingly and don't heat.</td></tr>
<tr><td>10</td><td>75</td><td>15</td><td>15 : 1</td><td>425 / 215</td><td>3</td></tr>
<tr><td colspan="6">Almond Oil
High in MUFA but still contains omega 6 fatty acids - use sparingly and don't heat.</td></tr>
<tr><td>7</td><td>65</td><td>28</td><td>28 : 1</td><td>430 / 220</td><td>6 / 12</td></tr>
<tr><td colspan="6">Walnut Oil
High in omega 6 and is very unstable - use sparingly and don't heat.</td></tr>
<tr><td>9</td><td>28</td><td>63</td><td>7 : 1</td><td>320 / 160</td><td>2 / 4</td></tr>
<tr><td colspan="6">Flaxseed Oil
Once opened, only lasts for 2 months. ALWAYS has to be refrigerated and can NEVER be used for cooking. After 2 months, can be used on your wood furniture for polishing. Although high in omega 3, most of it comes from ALA, which is a type of omega 3 your body cannot effectively convert to the type of omega 3s it needs (EPA and DHA).</td></tr>
<tr><td>9</td><td>18</td><td>73</td><td>0.3 : 1</td><td>225 / 110</td><td>2</td></tr>
<tr><td colspan="6">Hemp Seed Oil
Like flaxseed oil, should be refrigerated. ALWAYS has to be refrigerated and can NEVER be used for cooking. Rich in omega 3 fatty acids but most of it ALA, the type of omega 3 our body cannot effectively convert to the type of omega 3s it needs (EPA and DHA).</td></tr>
<tr><td>10</td><td>15</td><td>75</td><td>2.5 : 1</td><td>225 - 300 / 110 - 150</td><td>2 / 4</td></tr>
<tr><td colspan="6">Pistachio Oil
High in MUFA and omega 6 - use sparingly and don't heat.</td></tr>
<tr><td>15</td><td>54</td><td>31</td><td>31 : 1</td><td>325 - 350 / 160 - 175</td><td>6</td></tr>
<tr><td colspan="6">Pumpkin Seed Oil
Low smoke point, high in omega 6 - use sparingly and don't heat. It may interfere with some blood clotting medications (consult with your doctor before use).</td></tr>
<tr><td>17</td><td>20</td><td>63</td><td>20 : 1</td><td>250 / 120</td><td>6 / 12</td></tr>
<tr><td colspan="6">Peanut Oil
Possibly cold uses and for finishing meals, BUT: Peanuts are not paleo-friendly (legumes contain phytates, lectins and may contain aflatoxin). It's high in MUFA but also omega 6 - if not avoided, use sparingly. Keep in mind high smoke point or 450 F only refers to the REFINED version. It may contain herbicide and pesticide residues!</td></tr>
<tr><td>17</td><td>46</td><td>32</td><td>34 : 1</td><td>275 - 300 / 135 - 150</td><td>6</td></tr>
</table>

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Figure 56. Properties of different fat

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