PROTEIN RICH EXTRUDED SNACK FOOD FROM FINGER MILLET FLOUR, OAT FLOUR, POTATO STARCH AND WHEY PROTEIN ISOLATE BLENDS

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DEDICATED TO MY FAMILY AND MY SUPERVISOR

ABSTRACT

Extrusion cooking is a high temperature short time shear process used to transform raw ingredients into modified intermediate and finished products. It has been widely used in food industry as it offers continuous processing while maintaining significantly higher nutrient levels. Recent studies suggested that most snack foods +available in the market are categorized under the “unhealthy or junk food” category due to their higher fat, sugar and salt contents, and lower protein content. Hence for healthier snack option, it is necessary to fortify the formulation with proteins and other nutrients from selected sources and that can improve the health promoting quality of snack. The overall objective of this research was to prepare high-value protein-rich products through the use of extrusion processing.

To achieve this broad objective, specific blends of finger millet flour, oat flour, potato starch and whey protein isolate (W) were subjected to twin screw extrusion process with the specific objective of enriching the protein content of extruded snack product. Different blends of finger millet flour (F), oat flour (O), potato starch (P) and whey protein isolate (W) were prepared based on a D-optimal mixture design, with constrains: F (50-70%), O (10-30%), P (20-40%), and W (0-10%), followed by extrusion at screw speed of 100 rpm while temperatures in a extruder barrel were set to 80°C, 100°C, 120°C and 140°C from feeding zone towards the die. The resulting extruded products under the above conditions were found to have too high moisture content and water activity. Hence, the extruded products were dried at 55°C and 0.1 m/s air flow rate to reduce the final moisture content to 18% (dry basis) and water activity below 0.75 for shelf stability. Models were developed to predict drying times to reduce the product moisture to stable levels (water activity below 0.75). The results revealed that extrusion processing variables, viz. quantity of finger millet flour (F), oat flour (O), potato starch (P) and whey protein isolate (W) were found to have a significant ($p<0.05$) effect on extrudate’s drying process, the final product’s moisture content and water activity. Increase in the amount of whey protein isolate in the formulation significantly led to an increase in extrudate’s drying time ($p<0.05$). On the other hand, increase in potato starch proportion in the formulations significantly reduced the drying time.

The next phase of project was to develop snack products with good sensorial characteristics either by frying in oil or dry roasting in a microwave oven. For frying, dried

extrudates were deep fried in canola oil at 200 ± 1 °C for 330 s; and, for microwave roasting, they were heated for total treatment time of 100 s at 50% power level, and a sensory evaluation was performed to describe the acceptability of products. The sensory and analytical quality parameters of fried and roasted snacks were compared. The result showed that an increase in oat and finger millet flour content increased the hardness for both fried and microwave roasted products, whereas an increase in potato starch content decreased the hardness. Further, a* value of fried samples had a strong positive correlation with overall acceptability of test samples. This confirmed that oil content plays a significant role in modification of color & texture of fried samples in favor of their acceptability by consumers like other fried products available in market. While in case of microwave roasted extrudates, the value of L* was found to decrease with an increase in potato starch content in the formulation.

Overall, the research contributed to a better understanding of the extrusion process of high protein finger millet flour blends. The results demonstrated that products with higher protein content and good sensory characteristics could be prepared transforming a junk food to a nutritious snack. Together with post extrusion treatments including drying, frying or microwave roasting, good quality protein-rich extruded snack products were produced: microwave roasted extrudates were the preferred with better correlation of sensory properties with analytical parameters of color and texture. The results demonstrated the potential application of microwave roasting assisted extrusion instead of frying to get a healthier snack food development.

RÉSUMÉ

Cuisson-extrusion est un processus à haute température, et courte cisaillement de temps. Le procès est utilisé pour transformer des ingrédients brut, en produit modifier intermédiaire et termine. Le processus est largement utiliser dans l'industrie des aliments, car ça offre des traitements en continu, tout en significativement conservant les niveaux élevé des nutriments. Des études récentes, suggère que la plupart des collations disponible au marché sont dans la catégorie des aliments "malbouffe", a cause de haut niveau de graisse sucre et sel, sans la protéine nécessaire. Par conséquent, pour avoir plus d'option plus saine de collation, il est nécessaire de fortifier la formulation avec des protéines et d'autres nutriments provenant de sources sélectionnées et qui peut améliorer la qualité de collation de promotion de la santé. L'objectif global de cette recherche était de préparer des produits riches en protéines de haute valeur grâce à l'utilisation du traitement d’extrusion.

Pour accomplir cet objectif, des mélanges spécifiques de la farine du millet, la farine d'avoine, amidon de pomme de terre et isolat protéique de lactosérum (W) ont été soumis à double processus d'extrusion de vis avec l'objectif spécifique de l'enrichissement du contenu des protéines du produit de snack extrudé. Différents mélanges de farine du millet (F), la farine d'avoine (O), de l'amidon de pomme de terre (P) et isolat protéique de lactosérum (W) ont été préparé Conception optimale de D- mélange , avec contraintes : F (50-70 %), O (10-30 %), P (20-40 %), et W (0-10 %), suivi par l'extrusion à vitesse de vis de 100 rpm pendant que les températures dans un cylindre de l'extrudeuse ont été fixées à 80 ° C , 100 ° C, 120 ° C et 140 ° C à partir de l'alimentation vers la zone de la filière. Les extrudés obtenus dans les conditions ci-dessus se sont révélés d'être plus élevés dans la teneur en humidité et d'activité d'eau pour la stabilité de conservation. Par conséquent, les produits extrudés ont été séchés à 55 ° C et 0,1 taux m / s le débit d'air pour réduire la teneur en humidité finale à 18% (base sèche) et l'activité de l'eau en dessous de 0.75. Les modèles ont été développés pour prédire le temps de séchage afin de réduire l'humidité du produit à des niveaux stables (activité en eau inférieure à 0,75). Les résultats ont révélé que les variables de traitement d’extrusion, à savoir. La farine du millet (F), la farine d'avoine (O), de l'amidon de pomme de terre (P) et isolat protéique de lactosérum (W) ont été trouvés à avoir une augmentation significative ($p < 0{,}05$) effet sur le processus de séchage de l'extrudât, le contenu en humidité du produit final et de l'activité de l'eau. Augmentation de la

quantité de protéine de lactosérum isolé de manière significative dans la formulation conduit à une augmentation du temps de séchage de l'extrudât ($p < 0,05$). Cependant, l'augmentation des proportions d'amidon de pomme de terre dans les formulations a réduit significativement le temps de séchage.

La prochaine phase du projet était de développer des produits de collation avec de bonnes caractéristiques sensorielles, soit par friture dans l'huile ou grillage à sec dans un four MO. Pour la friture, extrudâtes séchés ont été frits dans l'huile de canola à 200 ± 1 ° C pendant 330 secondes, et, pour les micro-ondes torréfaction, ils ont été chauffés pendant la durée totale de traitement de 100 s au niveau de puissance de 50% et une évaluation sensorielle a été réalisée pour décrire l'acceptabilité des produits. Les paramètres sensoriels et analytiques qualité de snacks frits et rôtis ont été comparés. Le résultat a montré augmentation de l'avoine et le millet teneur en farine dureté accrue pour les deux produits frits et micro-ondes grillées, alors qu'une augmentation de pommes de terre teneurs en amidon a diminué la dureté. En plus, une valeur de * d'échantillons frits avait une forte corrélation positive avec l'acceptabilité globale des échantillons. Cette confirmé que la teneur en huile joue un rôle important dans la modification de la couleur et la texture des échantillons frits en faveur de leur acceptabilité par les consommateurs comme les autres produits frits disponibles sur le marché. Alors que dans le cas de micro-ondes extrudâtes torréfiés, la valeur de L * a été trouvé être diminué avec l'augmentation de la teneur en amidon de pomme de terre dans la formulation. Ce qui est arrivé principalement en raison de plus haut degré de gélatinisation de l'amidon pourrait avoir eu lieu pendant la torréfaction micro-ondes.

En concluant, la recherche a contribué à une meilleure compréhension du processus d'extrusion de haute teneur en protéines des mélanges de farine du millet. Les résultats ont démontré que les produits à plus forte teneur en protéines et de bonnes caractéristiques sensorielles pourraient être préparés à transformer une malbouffe à une collation nutritive. Ensemble, avec les traitements soumettre d'extrusion y compris le séchage, frire ou rôtir micro-ondes, des produits extrudés collation riche en protéines de bonne qualité ont été produites: micro-ondes extrudés grillées étaient les préférés avec une meilleure corrélation des propriétés sensorielles avec des paramètres d'analyse de couleur et de texture. Les résultats ont démontré l'application éventuelle de micro-ondes torréfaction extrusion assistée lieu de friture pour obtenir un développement des grignotines sain.

CONTRIBUTIONS OF AUTHORS

Some parts of thesis research work have been presented at scientific conferences and manuscripts have been planned for publication. The thesis is written in the manuscript style so that the chapters highlighting the thesis research could be suitably edited for publication. Two authors have been mostly involved in the thesis work and their contributions to the various articles are as follows:

Siddhesh Salunke is the M.Sc. candidate who planned and conducted all the experiments, in consultation with his supervisor, gathered and analyzed the results and drafted the thesis and the manuscripts for scientific presentations and publications.

Dr. Hosahalli S. Ramaswamy is the thesis supervisor, under whose guidance the research was carried out, and who guided and supervised the candidate in planning and conducting the research, as well as in correcting, reviewing and editing of the thesis and the manuscript drafts for publication.

LIST OF PUBLICATIONS AND PRESENTATIONS

Parts of this thesis have been prepared as manuscripts for publications in refereed scientific journals:

Salunke, S. and Ramaswamy, H. S., 2015. Drying characteristics of extruded finger millet based formulations and physical characteristics of dried extrudates. **(draft prepared)**

Salunke, S. and Ramaswamy, H. S., 2015. Effects of post drying processes viz. frying versus microwave roasting on dried extrudate's characteristics. **(draft prepared)**

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NOMENCLATURE

ANOVA	**Analysis of variance**
a_w	**Water activity**
BD	**Bulk density**
BS	**Breaking stress**
db	**Dry basis**
Df	**Degree of freedom**
ER	**Expansion ratio**
F	**Finger millet flour**
FR	**Frying**
H	**Hardness**
M	**Moisture content**
MR	**Moisture ratio**
MW	**Microwave**
NS	**Not significant**
O	**Oat flour**
P	**Potato starch**
QRT	**Quality rating test**
r	**Pearson's correlation coefficient**
R^2	**Coefficient of determination**
RR	**Rehydration ratio**
RSM	**Response surface methodology**
SOS	**Sum of square**
WPC	**Whey protein concentrate**
W	**Whey protein isolate**
wb	**Wet basis**
WSI	**Water solubility index**

CHAPTER 1

INTRODUCTION

Extrusion cooking is defined as a high temperature short time shear process used to transform raw ingredients into modified intermediate and finished products (Riaz, 2001). Generally it leads to several changes in the extrudate, including the gelatinization of starch, denaturation of protein as well as complete cooking and thereby resulting in a final product that may be ready to eat (Yu, 2011). Moreover, extrusion cooking of ready-to-eat products provide several advantages over conventional processing methods as it favors faster processing times, quality retention, lower processing costs and greater flexibility leading to more types of end-products (Forsido & Ramaswamy, 2011). Notably, decline of formal lunchtime eating is creating a new market segment and strong growth in the snack food market (Gill, 2013). Extrusion cooking has been adapted widely as a popular method for production of different food varieties, ranging from the simplest expanded snacks to the highly-processed meat analogues (Moscicki et al., 2013). Further Hernandez-Diaz et al. (2007) mentioned that it is a versatile and feasible alternative for manufacturing snacks and water reconstitutable foods.

Chapman and Maclean (1993) stated that young people categorised foods into healthy or junk food. In fact, most of the snacks, currently available in the market, are categorized under the unhealthy or junk food due to their higher fat, sugar and salt content whereas lower in protein content. And hence there is a necessity to fortify the extrusion feed formulation with proteins from selected sources for healthier snack option. Hypothetically, successful incorporation of high concentrations of protein greater than 20% and as high as 80% will increase utilization of proteins and improve the nutrient density of extruded snack and breakfast foods (Day & Swanson, 2013). Nutritionally finger millet is considered as a rich source of calcium, iron, protein, fibre and other minerals. Specifically, it doesn’t contain gluten which makes it ideal to use in the formulation for the people who are suffering from either celiac disease, gluten sensitivity or gluten intolerance. And hence these targeted group can also consume the product made up from millet without risking their life. Among cereals, oats contain the best amino acid composition profile in addition to an overall high protein content. The primary reason for better nutritive value of oats due to its major protein fraction is the salt-soluble globulin that makes it uniquely different from other cereals (Salehifar and Shahedi, 2007).

Changes in the utilization pattern of processed products and awareness among the consumers about the health benefits has played instrumental role in the gradually increasing demands of finger millet and other nutritionally important cereals i.e. oat. According to Deshpande & Poshadri (2011), the most popular raw materials for extrusion of food is cereals due to functional properties, low cost and ready availability. Recently, millets, viz. finger millet, foxtail millet, pearl millet and kodo millet, have received attention because of their high fiber content and thus, it offers several benefits with the physiology of the gut namely, easy bowl movement, lowering the absorption of the glucose, regulation of the microflora etc. Also the efforts have been under way to provide it to consumers in convenient forms. Since several studies have been carried out on these millets using extrusion cooking viz. finger millet (Dhurve et al., 2015; Sawant et al., 2013), pearl millet (Byung-Kee et al., 2004; Yadav et al., 2014), kodo millet (Geetha et al., 2014), and foxtail millet (Deshpande & Poshadri, 2011; Ushakumari et al., 2007).

Extrusion process is considered as an extremely complex process. Further, there are three general degrees of freedom to control the final properties of any product manufactured in a blending operation: the selection of raw materials, the ratios in which to blend them and the processing conditions used to manufacture them (Muteki et al., 2007; Yu, 2011). Understanding the relationships between the ingredients is quite necessary to achieve desired product quality targets and to develop new products (Forsido & Ramaswamy, 2011). Hence, the main focus of this research was to enhance the nutritional and functional properties of extrudates for the development of snack product. To achieve that, specific blends of finger millet flour, oat flour, potato starch and whey protein isolates were subjected to twin screw extrusion process under identical set of processing parameters (i.e. pressure, temperature and screw speed) with the objective of enriching the protein content of finger millet based flour mixtures. Overall, the research helped and contributed for a better understanding of the extrusion process for high protein content blends.

Therefore,

The proposed objectives of research were:

1. To study and characterize the drying behavior and moisture behavior of the extruded products, made from finger millet flour based blends, obtained using a twin-screw extrusion process.

2. To evaluate the influence of extrusion process variables on physical properties (expansion ratio, rehydration ratio, breaking stress, bulk density and color {L*, a* & b* value}) of dried extrudates, using response surface methodology (RSM) to understand the nature of the process and identify system variables.

3. To compare the quality parameters (sensory attributes as well as physical characteristics) of extrudates following post-extrusion drying process and finish frying versus microwave roasting.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Technology of extrusion, well-known in the plastics industry, has now become a widely used in the global agro-food processing industry particularly in the food and feed sectors, where it is referred as extrusion-cooking. The domestic market has been enriched with a category of high-quality products belonging to the convenience and/or functional food sector (Moscicki & Zuilichem, 2011). In addition, the interest behind the usage of extruders in the food industry stems from the fact that they are capable of blending diverse ingredients into novel food structures and hence may be useful in the development of functional foods (Brennan et al., 2013). Notably the current lifestyle has been characterized by limited free time and increased working hours. As a result, the consumers has turned toward the products which is ready to eat mainly snack foods. Apart from that, especially the children across the world are attracted to several snack products which are available with good sensory as well as visual attributes. These are the main dominating reasons behind the exponential growth seen in the production of snack products using several processes by food industries.

During extrusion process, basically food materials are compressed within a cylinder by a piston and forced through a shaping orifice. It can be made continuous by replacing the piston with a helical screw (Ilo et al., 2000). The process initiates with feeding of material into an inlet hopper and rotation of the screw made them to move forward. Hence the rotating screw transports material from inlet to discharge as a result of the slipping of material on the screw surface. The friction between material and screw surface results in shearing and heating of the material. As it reaches the die, the pressure increases to the level required to force the material through the die orifice (Moscicki & Zuilichem, 2011). The flash pressure reduction at the interface between the die face and the atmosphere, with the resulting evaporation of the water present, means that the molten product behind the die face then expands considerably as soon it comes out. Moreover, the rate of expansion depends on the rheological and thermal properties of the molten material and on the geometry of the shaping insert (Guy, 2001). And Moscicki &

Zuilichem (2011) mentioned that the yielded extrudates are structurally similar to a honeycomb, shaped by the bundles of molten protein fibers.

According to Bisharat et al. (2013), extrusion cooking has permitted a large number of food applications as a multi-step, multi-functional and thermal/mechanical process. The effects displayed by extrusion cooking on nutritional quality are ambiguous. Moreover the range of physical and chemical changes in the processed material principally depends on the parameters of the extrusion process and the construction of the extruder, which is its working capability. As a result, the changes (either beneficial or deleterious) occur in the profile of proteins and amino acid, carbohydrates, dietary fibre, vitamins, mineral content and some non-nutrient healthful components of food (Singh et al., 2007). Steel et al. (2012) indicated the range of beneficial effects resulting from the extrusion process includes destruction of anti-nutritional factors, gelatinization of starch, increased soluble dietary fibre and reduction of lipid oxidation. While, nutritional value of the protein has reduced due to Maillard reactions between protein and sugars. Further this loss mainly depends on the types of raw material, their composition and process conditions. Unfavorably, extrusion process will also have some degradation effects on heat-labile vitamins and consequently the loss of vitamins has been noticed to varying extents. One big advantage of extrusion cooking is its capability to produce a wide range of finished products with minimum processing times using inexpensive raw material (Riaz, 2013).

2.2 Snack food

Surprisingly not much is known about the snack food`s role in the overall diet cycle of young adults (Gill, 2013). Hartline-Grafton et al., (2004) mentioned that many studies carried out on the eating behavior and food choices have scarcely focused, specifically, on snacking patterns. However, snacks comprise a drastically increasing area of the food industry and people are consuming more snacks than before. Gill (2013) denoted the global snack market should be worth almost $300 billion by 2010 (Food Navigator-USA, 2008) according to ‘Snack Foods’ report by Global Industry Analysts.

Finger millet has gained importance because of its functional components, such as slowly digestible starch and resistant starch (Wadikar et al., 2007). Importantly, the small millet grains have longer storage life, and can be termed as famine reserve. Food uses of millets have, however, been confined only to traditional consumers; limited especially to areas of their cultivation, and still have remained underutilized (Patel et al., 2014). Approaching them using traditional as well as contemporary processing methods for preparation of value added and convenience products would certainly diversify their food uses. Their exploitation for preparation of ready-to-use or ready-to-cook products would help in increasing the consumption of millets among non-millet consumers and thereby nutritional security (Verma & Patel, 2012).

With the changes in scenario of utilization pattern of processed products and with the number of snacking opportunities on the rise, it is important to determine the effects of snacking on health. The survey carried out by Lloyd-Williams et al., (2008) examining the impact on coronary heart disease of replacing one ‘unhealthy’ snack with one ‘healthy’ snack suggests that snacking increases calorie intake and fat and salt levels in the body. However, healthy snacks help people meet the recommended daily intake for fruits, vegetables, and certain vitamins and minerals (Sebastian & Goldman, 2008). To a greater extent, cutting out unhealthy snacks and replacing them with healthy snacks had shown a positive effect on peoples’ health, although it is acceptable to have a less-than-healthy snack every once in a while.

2.2.1 Definition

Gatenby’s (1997) study, “Eating frequency: methodological and dietary aspects” with the goal of clarifying the terminology of eating patterns in order to determine the nutritional implications of increased eating frequency. Significantly, the research revealed that the difference between “snacks” and “meals” depends on the time the food is consumed and/or the nutrient composition of the food. Gatenby (1997) relates that most researchers define a snack as a smaller, less structured meal that is not eaten during regular meal times - breakfast (morning), lunch (midday), and dinner (evening). Furthermore, researchers generally categorize snacks as either “unhealthy” or “healthy” in order to study the effects of snacks on health (Lloyd-Williams et al., 2008).

2.2.2 Healthy snacks

Whole-grain foods, fruits and vegetables, nuts and seeds, and low-fat dairy products are categorised under the healthy snack (Lloyd-Williams et al., 2008). Further they are, commonly, lower in fat, sugar, sodium, and calories. When asked to define healthy snacks, the University of Newcastle students in Pei-Lin's (2004) study suggested vegetables, fruits, and foods with high-fiber, low-fat, and low-sodium levels (Gill, 2013).

2.2.3 Unhealthy snacks

Unhealthy snacks carry little nutritional value and usually contain a higher refined sugars, saturated fat, and salt (Lloyd-Williams et al., 2008). The study has defined and explained unhealthy snacks as: chocolate bars, chips, cakes, and pastries. Whereas Pei-Lin (2004) conducted a study that explored factors influencing the selection of healthy and unhealthy snacks among students at the University of Newcastle in Australia. Similarly, majority of respondents in this study also defined unhealthy snacks as foods with high levels of sugar and fat. However, processed foods had also included in the definitions of unhealthy snacks by many respondents.

2.2.4 Snacking and its importance in human life

Snacking is an effective way to fit extra nutrients into your diet and prevent overeating at mealtimes. According to a study published in "American Journal of Clinical Nutrition" in May 2010, approximately 97 percent of Americans getting an average of 24 percent of their calories from snacks (Popkin and Duffey, 2010). And hence it is crucial to choose healthy snack options.

The several advantages of snacking are listed below:

a) Prevents overeating

Generally, snacking helps in order to keep from getting overly hungry in between meals and then helps to avoid overeating at your next meal. For that, it's advisable to combine a carbohydrate-rich food like whole grains, fruits or vegetables with protein foods like nuts or dairy products for the most filling snacks.

b) Keeps blood sugar levels steady

As a result of snacking, which are having a consistent amount of carbohydrates, it helps in keep the blood sugar levels even. This is especially helpful for not only diabetics but also beneficial for people without diabetes too.

c) Provides nutrients

Healthy and nutritious snacks help in meeting our nutrient needs for the day. Fruits, vegetables, whole grains, low-fat dairy and nuts or seeds are belong to nutrient-dense food category.

2.3 Historical overview

The extrusion process of foods has already been practiced for more than one centur6y (Lusas and Riaz, 1994). At first, in 1935, the application of single-screw extruders for plasticizing thermo-plastic materials became more common as a competitor to hot rolling and shaping in hydraulic-press equipment. A plasticizing single-screw extruder is provided with a typical metering screw, developed for this application (Figure 1).

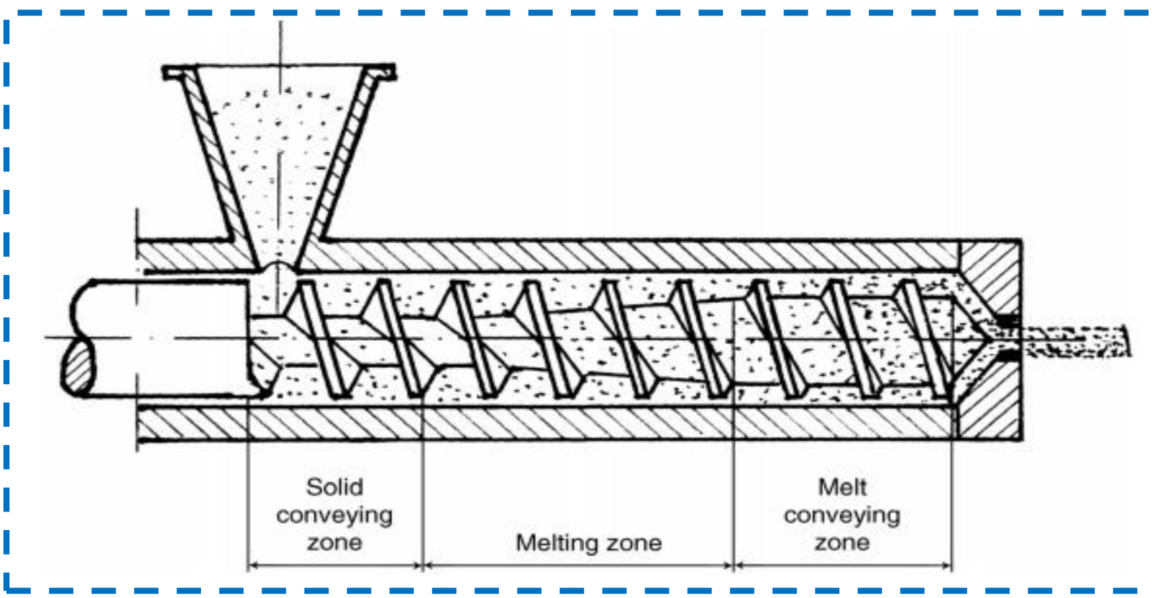

Figure 2.1 Typical plasticizing single screw extruder

(Source: Moscicki & Zuilichem, 2011**)**

In the mid-1930s, the first twin-screw extruders, both co-rotating and counter-rotating, had successfully developed for food production. Shortly after, single-screw extruders came into common use in the pasta industry for the production of spaghetti and macaroni-type products. In analogy with the chemical polymer industry, the single-screw equipment was used here primarily as a friction pump, acting more or less as continuously cold forming equipment, using conveying-type screws. It is remarkable that now-a-days the common pasta products are still manufactured with the same single-screw extruder equipment with a length over diameter ratio (L/D) of approximately 6–7. Finally, the equipment has been scaled up from a poor hundred kilos hourly production to several tons. However, the development work focusing on screw and die design has been still underway. Also the efforts have been more emphasizing for the improvement of process control, viz. sophisticated temperature control for screw and barrel sections, die tempering and the application of vacuum at the feed port (Moscicki & Zuilichem, 2011).

The first application of extruder in the food industry was by General Mills, Inc. who developed extruded ready-to-eat cereals in the late 1930's (Gill, 2013). Extrusion cooking was one of the technologies which has been catalyzed by World War II. The single-screw extruder was developed, in US in 1946, to cook and expand snacks made up from corn and rice. Further Moscicki & Zuilichem (2011) mentioned that in combination with an attractive flavoring this product type has still its popularity, and the method of producing snacks with single-screw extruder equipment is, in principle, still the same.

Introduction of twin-screw extruders for the combined process of cooking and forming of food products was achieved in the mid-1970s, partly as an answer to the restrictions of single-screw extruder equipment since twin-screw extruders provide a more or less forced flow, and partly because they tend to give better results on scale up from the laboratory extruder types in use for product development (Moscicki & Zuilichem, 2011).

2.4 Principles of extrusion technology

Extrusion technology has its importance in the food industry due to efficient manufacturing processes. Their main role was developed for conveying and shaping fluid forms of processed raw materials, such as dough and pastes (Gill, 2013). Further it offers a chance to use raw materials which have not previously displayed great economic importance (e.g., faba bean) or have even been regarded as waste.

2.4.1 Extrusion

According to Kearns (1999) extrusion cooking is defined as, "A continuous process by which moistened, expansible, starchy, and/or proteinaceous materials are plasticized and cooked by a combination of moisture, pressure, temperature, and mechanical shear." Alternatively it is a tool used to introduce thermal and mechanical energy to food and feed ingredients, forcing the basic components, such as starch and protein, to undergo chemical and physical changes to produce a predetermined shape of the final products.

2.4.2 Food extruder

Extruders are widely used to cook, to form, to mix, to texture and to shape food products under optimum conditions that favor quality retention, low cost and high productivity (Gill, 2013). Selection of the appropriate extruder configuration is critical for the success of extrusion. The four most commonly used types of cooking extruders currently are: single-screw 'wet' extruders, single-screw 'dry' extruders, single-screw interrupted-flight extruders, and twin-screw extruders. Once the appropriate extruder is selected, it must be assembled correctly and then adequately maintained (Riaz, 2001). The melt mass leaving the extruder takes more or less the shape of the extruder dies (nozzle); at the same time a lengthwise arrangement - an appropriate setting of the speed of a rotary knife cutter installed outside the die, controls the product length. This allows the production of miscellaneous shapes of extrudate such as balls, rings, stars, letters of the alphabet, and so on. However, old method of cutting previously shaped pieces of dough out of a sheet using roller-cutters is still in trend, as it needs very expensive dies and die-heads to form and cook the complicated shapes of snacks. Hence, knowledge of the physical behavior of a tempered dough and the unknown relations of the transport phenomena of heat, mass and momentum to the physical and physicochemical properties of the food in the extruder are also very important as same as extruder design (Moscicki & Zuilichem, 2011).

“A food extruder is a device that expedites the shaping and restructuring process of food ingredients” (Riaz, 2000). Moscicki & Zuilichem (2011) mentioned that although modern control techniques are very helpful in controlling the mass flow in single-screw extruders, it is always better to take an advantage of extruders with better mixing and steadier mass flow than offer by single screw equipment. A wide variety of extruder designs is offered for this purpose.

2.4.3 Extruder classification

a) Extruders are classified into two types according to operation: **Cold extrusion** and **extrusion cooking**

An application of c**old extrusion** has been most commonly used to form a specific shapes of extrudate at locations downstream from the die. In this process, feed is pumped through a die without the addition of external thermal energy. In common, one component of the final product is pumped through an opening of defined shape to create a continuous tube of the first component. Simultaneously, the second component of the final product is introduced just before the die and becomes a filler for the interior space within the outer tube. And finally, the tubular product is cut into appropriate lengths. The following are examples of food products that are usually prepared by cold extrusion process viz. pastry dough, individual pieces of candy or confections, pasta pieces, hot dogs, and selected pet foods (Singh & Heldman, 2009).

When thermal energy becomes a part of the extrusion process, the process is referred as **extrusion cooking**. Usually an addition of thermal energy introduced at the surface of the barrel. And mostly it is added to the extrudate during the extrusion process from an external source or may be generated by friction at internal surfaces of the extruder in contact with the extrudate. The friction between surfaces and ingredients within the barrel is caused for the creation of mechanical energy. And this created energy is dissipated in the form of thermal energy. The “cooking” process during extrusion is unique from most other thermal processes (Singh & Heldman, 2009).

b) Based on type of construction extruders are classified into: **Single screw** and **twin screw** extruder

c) Twin screw extruders are generally categorized according to the direction of screw rotation and to the degree to which the screws intermesh:

I Counter-rotating twin-screw extruder

- Screw of extruder rotates in the opposite direction.

II Co-rotating twin-screw extruder

- Screw of extruder rotates in the same direction.

Table 2.1 Typical process parameters of different kinds of extruders (Riaz, 2000)

Process	**Temperature (°C)**	**Max. Pressure (bar)**	**Moisture (%)**	**Max. Fat (%)**	**Cook* (%)**
Pellet press	60-100		12-18	12	15-30
Expander/pellet press	90-130	35-40	12-18	12	20-55
Dry extrusion	110-140	40-65	12-18	12**	60-90
Wet extrusion					
1) Single-screw	80-140	15-30	15-35	22	80-100
2) Twin-screw	60-160	15-40	10-45	27	80-100

*% cook represents starch gelatinization as measured by enzyme susceptibility

** Dry extrusion successfully processes full fat soy (18-20% fat) and other ingredients where final

d) These two categories can be further subdivided on the basis of position of the screw, in relation to one another, into: **intermeshing** and **non-intermeshing**.

The **non-intermeshing** twin screw extruder is like two single-screw extruders sitting side by side with only a small port ion of the barrels in common. In this type of extruders, extrusion is rely on friction and it is very similar to single screw extruders. Their design does not provide a positive displacement action for pumping the product forward. Hence in non-intermeshed extruders, neither pumping nor mixing is positive.

In **intermeshing** twin screw extruders, the screw's formation partially overlap each other in a barrel track. Thus it gives positive pumping, efficient mixing and self-wiping action (mainly in co-rotating machines while there has been limited mixing in counter-rotating machines). Hence, these extruders act as a positive displacement pump which forces material in the barrel between the screws to move towards the die by rotation of the screw. These characteristics plays a key role in differentiating types of extruders from non-intermeshing and single-screw machines.

2.5 Components of food extruder

Basically extruder is divided into four different sections or components as shown in Figure 2.2. Though these components appear in different ways and may be identified differently in various extrusion systems, depending on the specific equipment used and the product being manufactured.

1. Feeding (delivery) system

The first basic component of the extruder is a delivery system. The purpose of this section is to deliver, uniformly, the food ingredients/recipe or raw material to the next components. Consistent and uniform feeding of ingredients is necessary for the consistent and uniform operation of an extruder.

2. Preconditioning phase

Material from the delivery system is fed into the next section of the extruder, which is called the pre-conditioner. Usually it is not necessarily true that every kind of extruder will have a pre-conditioner. Most of the dry extruders and direct-expanded snack food extruders do not. However you can easily finds a pre-conditioner in the majority of the food and feed extruders.

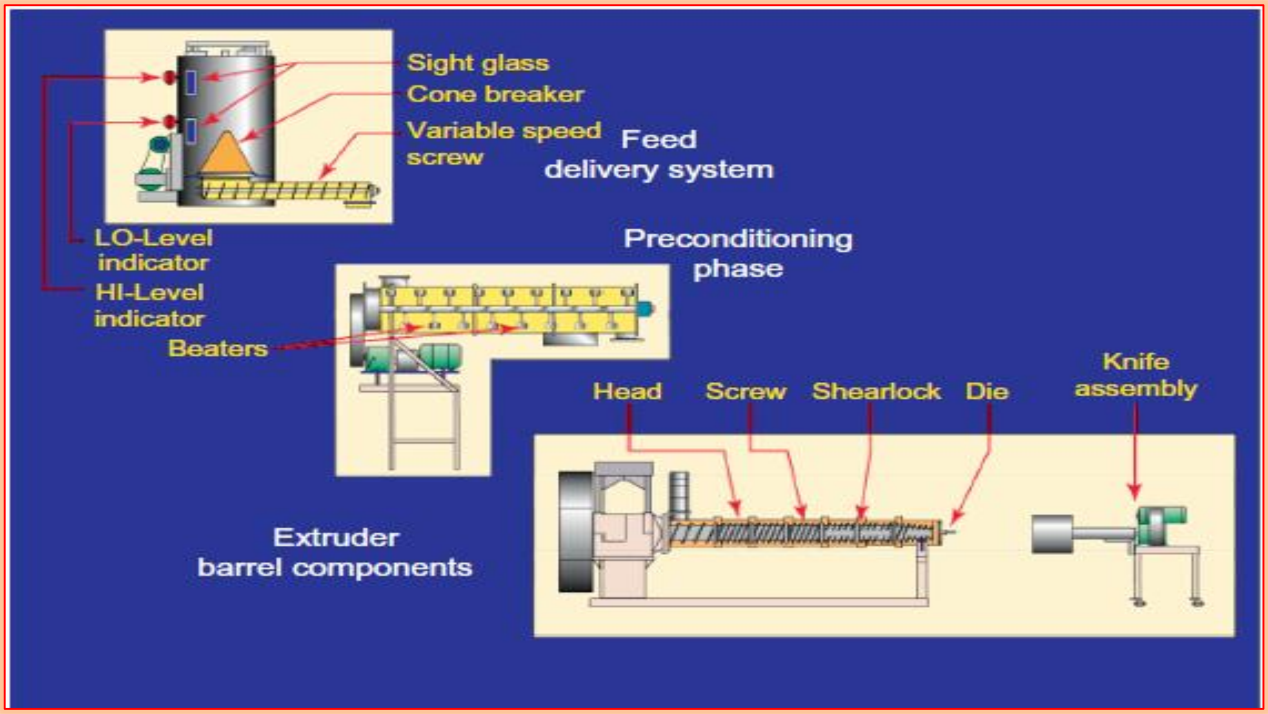

Figure 2.2 Extruder and its main components
(Adapted from: Riaz, 2013)

3. Extruder barrel

The barrel is the heart of the extrusion system. Most of the work is done by this section of the extrusion system. This section is made up of screws, sleeves, barrel heads, and dies. This section makes the extruder either a single screw or twin screw extruder. If we have two shafts parallel, then it will be a twin screw extruder, but if we have only one shaft, then it will be a single screw extruder.

4. Knife cutter

This is the fourth and last part of the extrusion system. The main function of this component is to cut the product to the desired length and shape. The knife assembly can be a different design depending on the manufacturer of the extrusion system. There is the option to use two, four, or six knives in the assembly.

2.6 Factors affecting extrusion cooking

The two most influencing factors which have its effect on the nature of the extruded product are the rheological properties of the food and the operating conditions of the extruder (Fellows, 2000).

2.6.1 Rheological properties of the food

The properties of the feed material have an important influence on the rheological characteristics of the product, especially the texture and also physical properties like color. The rheological properties depend on many factors such as:

1. Type of feed materials,
2. Moisture content,
3. Physical state of the materials,
4. Chemical composition, particularly (starch, sugars, protein, and fat),
5. pH.

2.6.2 Operating characteristics

The most important operating parameters in an extruder are:

1. Temperature,
2. Pressure,
3. Diameter of the die apertures,
4. Shear rate.

2.7 Advantages of extrusion processing

Popularity is gained by extrusion cooking over the last two decades for a number of reasons such as the following (Guy, 2001):

a) **Versatility:** a wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating conditions and shape of dies.

b) **Cost:** extrusion has lower processing costs and higher productivity than other cooking and forming processes.

c) **Productivity:** extruders can operate continuously with high throughput.

d) **Product quality:** extrusion cooking involves high temperatures applied for a short time, retaining many heat sensitive components of a food.

e) **Environmentally-friendly:** as a low-moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment costs and levels of environmental pollution.

2.8 Examples of extruded food products

There has been a wide variety of materials used for the manufacturing of extruded foods. Some commercial extruded products are listed in Tables 2.2 and 2.3.

Table 2.2 Extruded products for human consumption

(Source: Kokini et al., 1992)

Type	Example
Directly expanded	Breakfast cereals, corn curls
Unexpanded	Pasta
Half-products	Potato pellets
Co-extruded	Fruit-based cereal, jelly-filled cores
Modified	Starches, Fat mimics
Texturized	Meat analogs
Candy	Licorice, Chewing gum

Whereas extruded foods do not differ fundamentally in their ingredients from foods made by other processes but they do differ in that they generate different product types. The extrusion process usually provides the same color, flavors and the same or even improved nutritional qualities compared to other product types. The transformation of raw materials during processing is one of the most important factors that distinguish one food process and food type from each other.

Table 2.3 Examples of extruded foods according to type of the products [Source: Harper (1978), Harper (1989), Heldman and Hartel (1997) and Best (1994)]

Types of product	Examples
Cereal-based products	Expanded snack foods Ready To Eat (RTE) Puffed breakfast cereals Soup and beverage bases Weaning foods Pre-gelatinised and modified starches Crisp bread and croutons Pasta products Pre-cooked composite flours
Sugar-based products	Chewing gum Liquorice Toffee, caramel, peanut brittle Fruit gums
Protein-based products	Texturized vegetable protein (TVP) Semi-moist and expanded pet foods and animal feeds and protein supplements Sausage products Caseinates Processed cheese

The selection of optimal ingredients for processing is important in extrusion cooking. Classifying different types of material helps to develop an ideal process. Moreover, ingredients are classified according to either their components or their functionality. Early examples of extrusion processing include pasta products (macaroni, spaghetti, etc.) and pellets for conversion into ready-to-eat cereals. Current applications include commercial production of cereal based products (cornflakes, puffed rice, crisp-breads, snacks), fruit-based products (fruit gums, licorice, hard candies), protein-based products (textured vegetable proteins), animal feeds (pet foods), and spice-based products (flavors) (Singh & Heldman, 2009).

2.9 Formulation ingredients

All cereals containing good amount of starch can be extruded after making flour and conditioning to the required condition. The following are used in the present study.

I. Finger millet flour

II. Oat flour

III. Potato starch

IV. Whey protein isolate

2.9.1 Finger millet

Finger millet (*Eleusine coracana*) occupies highest area under cultivation among the small millets. Worldwide it is recognised by different name viz. ragi, African finger millet, red millet, caracan millet and koracan. It is consider to be a major source of dietary carbohydrates for a large section of society. Further it is comparable to rice with regard to protein (6-8%) and fat (1-2%) and is superior to rice and wheat with respect to mineral and micronutrient contents (Verma & Patel, 2012). Also it contains a good source of valuable micro-nutrients along with the major food compon0ents make it ideal to use for the food development. The previous research has linked minerals viz. magnesium and phosphorus to a reduced risk for heart attack and for the development of body tissue and energy metabolism respectively. Millets are also rich in phytochemicals (Shashi et al., 2007). Research on specific phytochemicals in foods and their effects on disease risk is limited, but there’s enough evidence, mostly from looking at the association between foods rich in phytochemicals and incidence of disease,to strongly suggest that consuming foods rich in these compounds may help prevent disease. The use of finger millet in food has showed enormous health benefits as it has potential to lower the risk of cardio-vascular disease (CVD) and type 2 diabetes.

In addition, finger millet is a rich source of carbohydrates and comprises of free sugars (1.04%), starch (65.5%), and non-starchy polysaccharides (Malleshi et al., 1986). Prominently dietary fiber content of finger millet (11.5%) (Gopalan et al., 2009) is much higher than the fiber content of brown rice, polished rice, and all other millets such as foxtail, little, kodo, and barnyard millet (Shobana et al., 2013). Also it contains important amino acids viz., isoleucine (4.4 g), leucine (9.5 g), methionine (3.1 g) and phenyl alanine (5.2 g) which are deficient in other starchy meals. The nutritional profile of finger millet is given in the Table 2.4.

Table 2.4 Composition of Finger millets (per 100 g edible portion, 12% moisture content) (Source: Gopalan et al., 2007)

No.	Particulars	Finger Millet	Wheat	Rice
1	Carbohydrate (g)	72.6	71.2	78.2
2	Protein (g)	7.7	11.8	6.8
3	Fat (g)	1.5	1.5	0.5
4	Crude fibre (g)	3.6	12.9	5.2
5	Ash (g)	2.7	1.5	0.6
6	Calcium (mg)	344	41	10
7	Phosphorus (mg)	250	306	160
8	Iron (mg)	6.3	3.9	0.5
9	Magnesium (mg)	130	120	32
10	Manganese (mg)	3.5	13.3	1.0

Generally finger millet is pulverized and utilized in the form of flour-based foods such as roti (unleavened pancake), kazhi (stiff porridge/dumpling) and kanji (thin porridge). Each of these foods have their characteristics features (Figure 2.3). Apart from that it also processed to prepare popped, malted, and fermented products. Other products that also made up from finger millets are papads (rolled and dried preserved product), noodles, soup, etc. (Shobana et al., 2013).

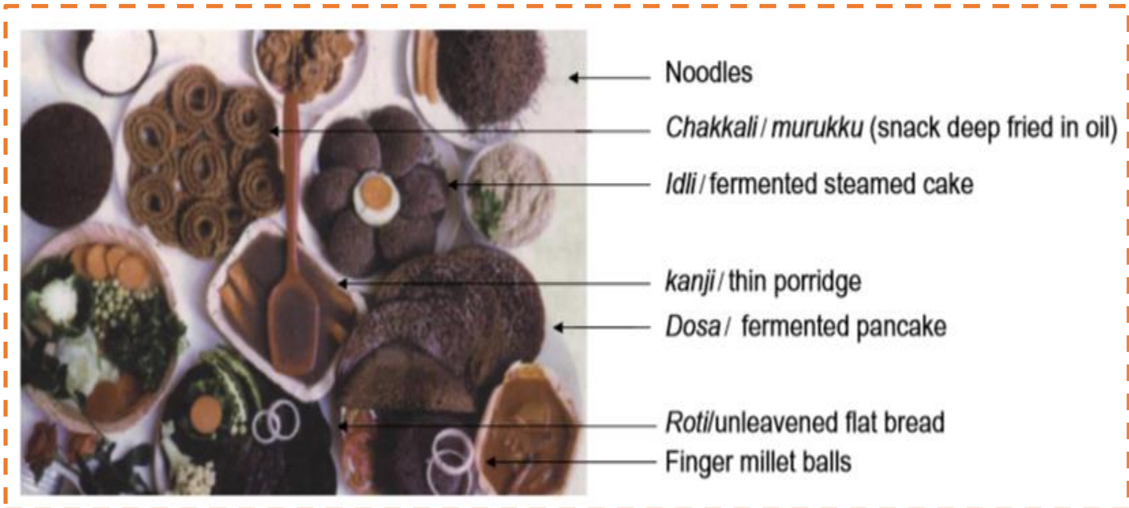

Figure 2.3 Traditional Indian foods prepared from finger millet

(Source: Photo courtesy Dr. N. G. Malleshi, former scientist, Department of Grain Science and Technology, Central Food Technological Research Institute, Mysore, India)
[Adapted from: Shobana et al., 2013]

2.9.2 Oat

Oat bran, possibly by virtue of its β-glucan content, exerts potentially beneficial physiological activity when consumed as a part of the human diet. The important nutritional attributes of oats relate to the lowering of blood cholesterol and sugar (El Shebini et al., 2014).

Oat contains a high percentage of desirable complex carbohydrates which have been linked to reduced incidence of different kinds of cancers. The presence of total and free sugars in oats is very low in comparison to other cereal grains (Lambo, 2004). Oats contain the best amino acid composition profile among all the cereal grains in addition to overall high protein content (Lapve et al., 1994). Oat protein is uniquely different from other cereals. The major protein fraction in oats is the salt-soluble globulin, which is probably the primary reason for the better nutritive value of oats.

The higher level of lysine in the globulin fraction than in the glutelin and prolamin fractions counteracts the better nutritious value of oats (Webster, 1986). Cereal proteins are generally considered to be limiting in lysine. Methionine, threonine, and isoleucine are secondary limiting amino acids in cereal proteins. The amino acid composition of oats is remarkably constant over a wide range of protein content with only a slightly negative correlation existing between total protein and lysine percentage. Oat proteins have good hydration and emulsifying properties and are heat stable, with oat globulin denaturation temperature about 114°C.

Whole-grain oats have the greatest percentage of fat among the major cereals with a good balance of the essential fatty acids, which are primarily unsaturated. The high content of oleic and linoleic acid, results in a favorable polyunsaturated to saturated fatty acid ratio of 2:2 (El Shebini et al., 2014). Oat flour also has antioxidant properties. On an equal weight basis, the purified oat antioxidant had effectiveness equal to that of commonly used commercial antioxidants such as BHA and BHT (Molteberg, 1995).

Lipase is one of the enzyme present in oats. In case of damaged or milled oats, it causes the rapid release of free fatty acids which is reason behind the development of off flavors. In industry, lipase activity is eliminated by heating the oat groats. Oats also contain high amounts of biotin, thiamin, niacin and pantothenic acid. Oat flour has been shown to be a complex collection of volatile flavor components. Nitrogen heterocycles, formed from Maillard reactions and lipid oxidation products are the key compositional type's off-flavor volatiles. Heat induced reactions of precursors native to the oat groats are primarily responsible for the development of oat flavor during its normal processing into commercial food products (Salehifar & Shahedi, 2007).

2.9.3 Potato starch

Starch is the main component of the final product due to its ability to provide the underlying structure (Guy, 2001). Usually the extrusion makes starch granules get gelatinized and dispersed, so it resulting in the formation of a continuous phase of the melt inside the extruder. Yu (2013) denoted that this may leads to decrease in average molecular weight, which allows for optimum formation and stability of air cells at the die exit. Both amylose and amylopectin are needed to give the best expansion characteristics (Huber, 2001).

Starch is contained in a large variety of plant crops, such as cereals (50-80% starch), legumes (25-50% starch) and tubers (60-90% starch) (Harper, 1989). Potatoes' starch granules are roughly twice as big as other starch granules (tapioca or grain starches) resulting in much higher water absorption capacity and better texture. It is a very refined starch, containing minimal protein or fat (Wischmann et al., 2007). These properties make the flour a clear white colour, and the cooked starch typical characteristics of neutral taste, good clarity and transparency, high binding strength, long texture and a minimal tendency to foaming or yellowing of the solution (Bergthaller et al., 2007).

Potato starch contains approximately 800 ppm phosphate bound to the starch; this increases the viscosity and gives the solution a slightly anionic character, a low gelatinisation temperature (approximately 60 °C) and high swelling power (Wondimu et al., 1996). Due to the above characteristics, the potato starch has widely usage in the food industry as a water binder, thickener, anti-caking ingredient, bulking ingredient and gluing agent.

2.9.4 Whey protein isolate (W)

The general term “Whey” is typically denotes the translucent liquid part of milk that remains following the process (coagulation and curd removal) of cheese manufacturing. Further, proteins are separated and purified from the liquid using various techniques and yielding into different concentrations of whey proteins (Hoffman & Falvo, 2004). Whey is considered as one of the two major protein groups of bovine milk, accounting for 20% of the milk while casein accounts for the remainder (Marshall, 2004). Generally, the constituents of whey protein provide high levels of the essential and branched chain amino acids. Moreover Hoffman & Falvo (2004) relates the bioactivities of these proteins with many beneficial properties. Also it is considered to be a rich source of vitamins and minerals.

Significant removal of fat and lactose had been found during processing of whey protein isolate (W). W contains a higher percentage of pure protein (90% or higher) and can be pure enough to be virtually lactose free, carbohydrate free, fat free, and cholesterol free. As a result, individuals who are lactose intolerant can often safely take these products (Geiser, 2003). Although a high concentration of protein is present, it usually undergoes denaturation during the extrusion manufacturing process. Thus it might result in the reduction of effectiveness.

Whey protein is most recognized due to its applicability in sports nutrition due to their high bioavailability. And so they are very quickly absorbed into the body. Further they have a high concentration of branched-chain amino acids (BCAAs) which are highly concentrated in muscle tissue, and are used to fuel working muscles and stimulate protein synthesis (MacLean et al., 1994). W has ability to be digested very rapidly and help return the post-workout body back from a catabolic (muscle-wasting) state to an anabolic (muscle-building) state. That's the key point of interest for its popularity among athletes today. According to Hoffman & Falvo (2004), W has its widely use in infant formula to provide a natural source of amino acids for optimal growth and development, as well as for protein fortification of bars, beverages, dairy products, extruded snacks and cereals and other food products.

2.10 Response surface methodology

Response surface methodology (RSM) was developed by Box and Wilson (1951) who suggested to use a first-degree polynomial model to approximate the response variable. They acknowledged that this model is only an approximation, not accurate, but such a model is easy to estimate and apply, even when little is known about the process. Yu (2013) mentioned that it is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. Considerably, RSM is mostly used in situations where several input variables (independent variables) influence potentially the quality characteristics (response variables) of the product or process. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. For that, Box and Wilson (1951) suggested to use of a second-degree polynomial model and acknowledged that this model is only an approximation; however, this model was easy to estimate and apply, even when little was known about the process (Myers et al., 2009).

D-optimal mixture design is an experimental design used in RSM. Generally it is used under the circumstances of either limited budget or due to time limitation; it can't allow to run a completely replicated factorial design (Ruseckaite et al., 2014). For example, suppose we want to study the response to three factors: A with three levels, B with four levels, and C with eight levels. To perform one complete replication of this experiment, it would require 3 x 4 x 8 = 96 runs. And hence it requires much long-lasting work. To avoid that, the D-optimal design algorithm provides a reasonable choice which can be easy to accomplish during permitted time interval.

PREFACE TO CHAPTER 3

Extrusion cooking is defined as a high temperature short time shear process used to transform raw ingredients into modified intermediate and finished products. It has been widely used in food industry as it offers continuous processing while maintaining significantly higher nutrient levels. Recent studies suggest that most snack foods available in the market are grouped under the “unhealthy or junk food” category due to their higher fat, sugar and salt contents, and lower protein content. Hence for healthier snack option, it is necessary to fortify the formulation with proteins and other nutrients from selected sources that can improve the health promoting quality of snack. The value of extruded snack foods enhanced by blending ingredients that are rich in proteins, minerals along with simple and complex carbohydrates.

The focus of Chapter 3 is to understand the relationship between the extrusion processing variables namely the quantities or proportions of finger millet flour, oat flour, potato starch and whey protein isolates (W) in the feed mix on the properties of extruded products when subjected to twin screw extrusion process. The ultimate objective was to produce a range of protein-rich gluten-free extruded products. The proportions of these four ingredients were selected using a unique D-Optimal constrained mixture design with a constrained level for finger millet flour (50-70%), oat flour (10-30%), potato starch (20-40%) and W (0-10%) on the physical properties of the dried extruded products.

A part of this research was presented at the 2014 conference Research Feeding Industry (RFI) held in Montreal, Canada. The experimental work and data analysis were conducted by candidate under the supervision of Dr. H. S. Ramaswamy. Based on this study, the following manuscript has been prepared for publication.

A manuscript draft has also been prepared for publication:

Salunke, S. and Ramaswamy, H. S., 2015. Extrusion and drying characteristics of finger millet based formulations (draft).

CHAPTER 3

EXTRUSION AND DRYING CHARACTERISTICS OF FINGER MILLET BASED FORMULATIONS AND PHYSICAL CHARACTERISTICS OF DRIED EXTRUDATES

Abstract

Different blends of finger millet flour (F), oat flour (O), potato starch (P) and whey protein isolate (W) were prepared based on a D-optimal mixture design, with constrained levels for finger millet flour (50-70%), oat flour (10-30%), potato starch (20-40%) and W (0-10%). Each formulation mixture was extruded under identical set of conditions (temperature, screw speed and die diameter) followed by air-drying at 55°C in a convection oven with the controlled air flow rate of 0.1 m/s. During drying process, the moisture content and water activity of test samples were evaluated every 15 min till the targeted final moisture content of the extrudates reach to 18% (db) in the sample. The obtained data were used to characterize the drying kinetics. A model based on the D-optimal mixture design was developed for predicting the moisture ratio of the products. Moreover ANOVA and model generated response surfaces plot that served to evaluate the significance of independent and interaction effects of extrusion process variables on the product‘s various physical properties such as expansion ratio, breaking stress, bulk density, rehydration ratio and color (L*, a* and b*). The linear terms of all the process variables had showed significant effect ($p < 0.01$) on expansion ratio values. The formula containing 50% F, 20% O, 20% P, and 10% W was selected to yield a product with high protein content (19.15 g/100g).

3.1 Introduction

Extrusion cooking is one of the most efficient and versatile food processing technologies that can be used to produce pre-cooked and dehydrated foods (Onyango et al., 2005). Further it has been widely used in food industry due to continuous processing as well as its ability to maintain significant nutrient levels (Yu, 2011). The current way of life, which is characterized by limited free time and increased working hours, has turned consumers to consumptions of ready-to-eat products. In addition, children, worldwide, are attracted to several snack products which are particularly tasty and easy to be consumed. However, the nutrition profiles of this kind of products are generally associated with low proportion of protein. Additionally, nowadays, there is an increasing trend for the consumption of high-value food products. In order to combine the need for the consumption of high-value food products, beneficial ingredients are added to the extruded mixtures. However it is necessary to use supplementary ingredients which are familiar and acceptable to consumers, so that the final product is as similar in characteristics as possible to the without supplemented food product (Krishnan, 1987). Over the long haul, extrusion cooking is a widely studied process; however, various nutrients enriched extrudates have not been extensively examined (Bisharat et al., 2013).

Finger millet (*Eleusine coracana L.*) is important millet grown extensively in various regions of India and Africa, constitutes as a staple food for a large segment of the population in these countries. Moreover, changes in the utilization pattern of processed products and awareness among the consumers about the health benefits has played instrumental role in the gradually increasing demands of finger millet and other nutritionally important cereals. It is known for several health benefits and some of the health benefits are attributed to its polyphenol and dietary fiber contents (Mathanghi et al., 2012). The incorporation of dietary fibers into extruded products plays an important role on their structural characteristics. Few studies reported that high levels of fiber have often resulted into a compact, tough, non-crisp and undesirable texture (Lue et al., 1991). Oat flour, followed by finger millet flour, was used as a second prime constituent. Salehifar and Shahedi (2007) mentioned that oat bran, possibly by virtue of its β-glucan content, exerts potentially beneficial physiological activity when consumed as part of the human diet. In addition, the important nutritional attributes of oats helps in lowering of blood cholesterol and sugar (Webster, 1986). Importantly, it contains a high percentage of desirable complex carbohydrates which have been linked to reduced incidence of different kinds of cancers. Another significant feature is total and free sugars presence in very low proportion compared with other cereal grains (Lambo, 2004).

The most common ingredient used for an extrusion is starch. It occurs primarily in cereal grains and potatoes. Also it takes the form of granules of different and characteristic shape, depending on the origin as well as on the variety and type of fertilization (Moscicki et al., 2013).

The extrusion processing of starchy materials certainly impacts the changes in product viscosity (pasting characteristic) after dissolving in water. At a temperature specific to each type of starch, known as the gelatinization temperature, starch granules irreversibly lose their regular shape and properties (such as insolubility in cold water). These changes are connected to the increase in viscosity of the heated solution and greater starch solubility in water. Most of these characteristics have an advantage in the production of the so-called functional starches used as thickeners for soups, sauces, dessert sand dishes served cold. This feature is very important for the technological point of view. To take the advantages offered by starch during extrusion, it was added in the form of potato starch. Now-a-days extruded snacks available in the market usually fortified using different source of protein to enhance the nutrient density. Protein addition to starch increases sites for cross-linking and affects the textural quality (Yadav et al., 2014). And hence the plan of our research was to add whey protein isolate (W) as an external source to enrich the protein content of extruded snack.

Further, moisture content of low temperature extrudates are too high for achieving shelf stability, and therefore, post-extrusion drying is the final step in production of shelf stable extruded products. Majority of cases reported the water activities of extruded samples were found to be more than 0.9. The maximum water activity value for shelf stability of the dried products is 0.75 at room temperature. Hence it is necessary to find drying conditions that would reduce the water activity of extruded samples to safe levels in order to provide shelf-stability. Secondly, in protein rich extruded products, the protein interaction with carbohydrate significantly affects their functional properties (Onwulata et al., 1998) and subsequently their post-extrusion drying behavior. Depending on the extrusion conditions, whey protein isolate enriched starch formulations will have their own unique properties under different drying conditions. As the protein level in a recipe is increased – usually at the expense of starch – there are changes in product expansion, texture and durability. Additionally the modification of these properties could play a significant role on drying behavior and characteristics of protein rich extruded products. Therefore it is important to evaluate drying conditions for better shelf life stability and quality of extrusion-dried products.

Consequently, the objectives of this research was to evaluate the drying kinetics as well as physical characteristics of the dried extruded products related to extrusion process variables.

The ultimate objective of research is production of gluten-free high protein dried extruded products from finger millet flour based blends.

3.2 Materials and Method

3.2.1 Materials

Finger millet flour from AAHA FOODS (Toronto, Canada) was purchased locally (composition mentioned by the manufacturer: protein: 7 %, fat: 2.3%, carbohydrate: 24% and dietary fiber: 48%). Oat flour and potato starch were procured from the local store known as bulk barn located at Vaudreuil-Dorion (composition of oat flour mentioned by the manufacturer: protein: 13%, carbohydrate: 23%, fat: 10% and fiber: 40%) and (composition of potato starch mentioned by the manufacturer: carbohydrate: 26%). Meanwhile whey protein isolate (W) was also bought from the bulk barn (Vaudreuil-Dorion, Montreal), which had 90% protein.

3.2.2 Experimental design

This study was conducted with 20 suggested experimental conditions according to a D-optimal mixture design using Design Expert Software (Version 9.0.3 State-Ease, Inc., Minneapolis, MN) with basically four variables and their predetermined set of constrained value (Table 3.1). Experiments were performed in a random order including replicate points to minimize the effect of experimental errors. The independent variables with their constrained values were finger millet flour (50-70%), oat flour (10-30%), potato starch (20-40%) and W (0-10%).

3.2.3 Raw material blend preparation for extrusion

An Excel worksheet was used to record the quantities of the finger millet flour, oat flour, potato starch and W (based on a mass balance approach). The details of the different test run with coded (and real) values of the process variables as well as the amount of ingredients added for a 700 g batch (excluding the 300g water and 14g of salt added to each formulation) are shown in Table 3.1. The flours, salt and water were mixed by using a Hobart mixer (Hobart Food

Equipment Group Canada, North York, ON) operating at a medium speed. The wetted blends were mixed for 20 min in the Hobart mixer and then allowed it to sit for overnight.

Table 3.1 Experimental D-optimal design with coded and (actual) values for finger millet flour, oat flour, potato starch and W, along the details of the quantities of salt and water added for each 700 g batch of ingredients (excluding salt & water proportion)

Run	Finger millet flour % (g)	Oat flour % (g)	Potato starch % (g)	W % (g)	Salt (g)	Water (g)	Moisture content (% wb)
1	50 (350)	15 (105)	25 (175)	10 (70)	14	300	37.2
2	50 (350)	20 (140)	30 (210)	0 (0)	14	300	38.4
3	50 (350)	20 (140)	30 (210)	0 (0)	14	300	38.0
4	50 (350)	10 (70)	40 (280)	0 (0)	14	300	38.5
5	60 (420)	10 (70)	30 (210)	0 (0)	14	300	38.0
6	50 (350)	10 (70)	30 (210)	10 (70)	14	300	37.9
7	52.5 (367.5)	12.5 (87.5)	32.5 (227.5)	2.5 (17.5)	14	300	38.6
8	52.5 (367.5)	22.5 (157.5)	22.5 (157.5)	2.5 (17.5)	14	300	38.1
9	65 (455)	10 (70)	20 (140)	5 (35)	14	300	38.5
10	50 (350)	30 (210)	20 (140)	0 (0)	14	300	39.1
11	50 (350)	30 (210)	20 (140)	0 (0)	14	300	38.1
12	60 (420)	10 (70)	30 (210)	0 (0)	14	300	38.5
13	60 (420)	20 (140)	20 (140)	0 (0)	14	300	38.2
14	50 (350)	20 (140)	20 (140)	10 (70)	14	300	38.3
15	55 (385)	10 (70)	25 (175)	10 (70)	14	300	38.1
16	60 (420)	20 (140)	20 (140)	0 (0)	14	300	37.9
17	55 (385)	15 (105)	25 (175)	5 (35)	14	300	38.9
18	50 (350)	10 (70)	40 (280)	0 (0)	14	300	39.3
19	70 (490)	10 (70)	20 (140)	0 (0)	14	300	38.22
20	60 (420)	10 (70)	20 (140)	10 (70)	14	300	37.8

3.2.4 Extrusion process

Extrusion process was performed in a co-rotating twin screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P. R. China), consisting of three independent zones of controlled temperature in the barrel. The diameter of the screw was 30 mm. The length to diameter ratio of the extruder barrel was 20:1. The diameter of the hole in the die was 5 mm with a die length of 27 mm. The screw speed and the temperature of the third barrel section (metering section) were adjustable according to the desired levels. The process of feeding had done manually through a conical hopper, keeping the flights of the screw fully filled and avoiding accumulation of the material in the hopper.

Once the stable condition has attained, extruded products were collected and further cool dried under mild air flow conditions at room temperature overnight and then further drying process had completed to get a final moisture content of 18% (dry basis) by an air convection dryer at 55 °C with an air flow of 0.1 m/s. Dried samples were stored in air tight plastic containers at room temperature and used for further analysis purpose.

3.2.5 Drying principle

Drying is a process to obtain dried product by removing water from the wet product. When the wet material is placed in the low water partial pressure medium at the same temperature, it allows the wet material to dehydrate until the equilibrium is achieved. The medium used for drying are high vacuum air atmospheric air pressures, superheated steam, hot oil, solvents and solutions (Karel and Lund, 2003).

Food dehydration is a balance between the foodstuff's water and the drying medium`s water. During the process, the water is evaporated to the drying medium. During the air-medium drying process, the water is removed from the food surface to the air till the equilibrium is achieved, leaving behind the moist air. These equilibrium conditions represent a balance between moist vapor pressure at the surface of food and that of the surrounded air (Ramaswamy and Marcotte, 2004). The moisture is removed continuously during the evolution of the drying process. But the drying rate doesn't remain constant throughout. In the later stages, much less moisture is removed.

3.2.6 Tray Dryer

For sample drying, a pilot scale tray dryer was used (Figure 3.1). The tray dryer was operated at 55°C with a target to have a final moisture content of 18% (db) in the sample. Fresh air entered the cabinet through a heater and the hot air was blown across the food trays and vented out through an exhaust at the opposite end. There was no recirculation of the air. The weight of test sample in the dryer was continuously monitored with the help of a weighing balance placed in the lower compartment of the drier with the drying tray resting on the balance through attachment by a vertical rod.

Figure 3.1: Tray Dryer at Pilot Plant (McGill University)

3.2.7 Determination of moisture content

The moisture content was measured gravimetrically by the AOAC-984.25 (AOAC 1995) method: measured amount of sample was put into a glass pan and dried in a conventional oven (Fisher Scientific Isotemp Oven, Asheville, North Carolina) at 105 ± 1°C until it attained constant weight.

- The moisture content M (% wet basis) was calculated as follows:

$$M\ (\%\ wb) = [\frac{(Wo - Wd)}{(Wo - Wp)}]\ x\ 100 \qquad \ldots\ldots\ldots (3.1)$$

where:

Wo = Weight of the sample with the pan before dried (g),

Wd = Weight of the sample with the pan after dried (g),

Wp = Weight of the pan (g).

The moisture content M (% dry basis) was obtained as follow:

$$M\ (\%\ db) = [\frac{M\ (\%wb)}{[100 - M\ (\%wb)]}] \qquad \ldots\ldots\ldots (3.2)$$

3.2.8 Determination of water activity (a_W)

Water activity is defined as the vapor pressure of water above a sample divided by vapor pressure of pure water at the same temperature. The water activity of water is exactly one. It is a dimensionless quantity and is used to represent the energy status of the water in a system. It is and indicator of the dryness and is commonly used in the food systems. The shelf life of product is higher with an optimum water activity.

The main aim of food science and technology is to maintain the food quality and safety. By measuring water activity of the food; the stability of food, growth of microorganisms (spoilers and pathogens) and degradation processes (enzymatic and non-enzymatic deteriorative reactions) can be estimated. The pathogenic bacteria generally require water activity of less than 0.90 whereas mold growth requires water activity of 0.80 except that of *Zygosaccharomyces rouxii* which is capable of growing at water activity of 0.61-0.65 (Gill, 2013). The water activity of food greatly affects the growth of microorganisms and it is the principal factor which is linked to the microbial growth. A water activity level of 0.75 is normally considered to be a safe level, because most of bacteria will not grow and cause problems below this level (Ramaswamy and Marcotte, 2006).

The water activity was measured by a water activity analyzer (ROTRONIC HygroLab 3, Rotronic Instrument Corp., NY), at room temperature 25°C, samples were put into the chamber of the water activity analyzer until the signal of equilibrium appeared, water activity value was recorded.

3.2.9 Determination of moisture ratio (MR)

Moisture ratio is the percentage of free moisture left in the products, it can be described as following:

$$MR = \left[\frac{(Mt - Me)}{(Mi - Me)}\right] \quad \text{......... (3.3)}$$

where:

Mt = moisture at time t,

Me = moisture at equilibrium condition,

Mi = moisture at initial time.

3.2.10 Color

Each color has its own distinct appearance, based on three elements: hue, chroma and value (lightness). By describing a color using these three attributes, you can accurately identify a particular color and distinguish it from any other. The CIE, or Commission Internationale de l'Eclairage (translated as the International Commission on Illumination), is the body responsible for international recommendations for photometry and colorimetry. In 1931, the CIE standardized color order systems by specifying the light source (or illuminants), the observer and the methodology used to derive values for describing color.

The CIE Color Systems utilize three coordinates to locate a color in a color space. These color spaces include:

• CIE XYZ

• CIE L*a*b*

• CIE L*C*h°

The color of extrudate was assessed using a Tristimulus Minolta colorimeter CM-500d (Optical Sensor, Hunter Associates Laboratory Inc., Reston VA, USA) using an aperture of 1.2 cm diameter. In the Minolta colorimeter, the color of a sample is represented by the three color parameters: L*, a* and b* which were recorded for each sample. The L* value gives a measure of the product lightness from 100 for perfect white to 0 for black, as the eye would see it. The redness/greenness is denoted by a* values (ranging from negative values on the red side to the positive values on the green side) and yellowness/blueness are denoted likewise ranging from negative to positive b* values.

3.2.11 Breaking stress

Breaking stress (BS) was measured in a 3-point bending test (Zasypkin and Lee, 1998) using the TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK.) equipped with a 20 kg load cell. The extruded product was placed on two rounded stands (bridge) 30 mm apart. A rounded plunger was made to push the sample at the middle of the bridges at 40 mm/min until breakage occurred. The breaking stress was determined as the breaking force (N) per unit cross-section area (mm^2). Ten measurements were made on each product and the average value was used.

3.2.12 Expansion ratio (ER)

Expansion ratio (ER) is defined as the ratio of the diameter of the extrudate to the diameter of the die (Jyothi et al., 2009). It is a factor used to describe the expansion of the product. In order to determine the ER, the diameter of 10 randomly selected samples were measured from each run using a digital caliper and the average value was used.

- ER was calculated as follows:

$$\mathrm{ER} = \left[\frac{Diameter\ of\ the\ extrudate}{Diameter\ of\ the\ die}\right] \qquad \text{………... (3.4)}$$

3.2.13 Bulk density (BD)

Bulk density (BD) describes the product density and also can describe the expansion of the product. It was measured by the displacement method (Yu, 2011). Extrudates were cut into strands, about 25 mm long, and about 15g strands were taken and weighed (M) and placed in a 100 mL measuring cylinder. Coriander seeds were added to fill up the cylinder up to the mark. Then the extrudate samples were separated and the volume of the coriander seeds was measured in the same cylinder (V).

- BD was calculated as follows:

$$BD = [\frac{M}{(Vvc - Vcm)}] \quad \text{………... (3.5)}$$

where:

M = weight of extrudates (g),

V_{vc} = Volume of the volumetric cylinder up to which the filling material was added (100 ml),

V_{cm} = Volume of coriander seeds when extrudates were taken out from volumetric cylinder (ml).

3.2.14 Rehydration ratio (RR)

Air dried sample (15 g, 18% moisture db) of extrudates were weighed (M1) and placed into 500 ml of water at room temperature for 15 min. The water was then drained and the rehydrated sample was weighed (M2).

- The rehydration ratio (%) was defined as:

$$RR = [\frac{M2 - M1}{M1}] \times 100 \quad \text{………... (3.6)}$$

where:

M1 = Initial weight of extrudates (g),

M2 = Weight of rehydrated extrudates (g).

3.2.15 Regression modelling and statistical analysis

The second order polynomial equation fitted with coded variables was:

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} x_i x_j$$

………... (3.7)

where:

Y represents the experimental responses (BS, BD, color, RR and ER),

Bo, Bi, Bii and Bij are constants and regression coefficients of the model,

Xi and Xj are independent extrusion processing variables,

n is number of processing variables (here n = 4)

The entire model includes linear, quadratic, special cubic and cross-product terms. Experimental data were analyzed using Design-Expert 9.0.4 (Stat-Ease Inc. Minneapolis, MN) and Microsoft Excel's 2013 Version. Design-Expert was used to solve the second order polynomial regression equation and Excel was used to investigate the effects of the four independent input variables of finger millet flour content, oat flour content, potato starch content and whey protein isolate content on the physical properties (BS, BD, ER, RR and color) of extruded products. Analysis of variance (ANOVA) was employed to justify the model goodness of fit as well as significant effects of independent variables on responses.

3.3 Results and Discussion

3.3.1 Drying kinetics

Table 3.2 summarizes the basic data on the moisture content of the extruded products immediately after it was removed from the extruder. It can be seen that the extruded product has an approximate dry basis moisture content in the range of 30-50% db (Table 3.2) and as presented later the protein content is in the range 6 to 20 g/100 g. This means, these formulations had yielded a protein rich product; however, higher moisture content of extruded product make it unstable and prone to spoilage during storage.

The experimental arrangement (test run number), data on moisture content, water activity and drying time are shown in Table 3.2. Some of the moisture in the feed formulation was evaporated when they exited the extruder, this can be seen by the comparison of moisture content in the raw material and the extrudate. For example in run 1, the moisture content in the raw material was 37.2% on wet basis (Table 3.1), which is equal to 59.3.% on dry basis, while the moisture content after extrusion came down to 44.7% on dry basis, the difference before and after extrusion process caused by the moisture evaporation when the extrudate exited the die.

The drying is applied in the food, pharmaceutical, and chemical industries and consumes up to 10% of the total energy used in the food sector (Mujumdar, 1997). The bulk drying conditions of new materials need to be determined for optimal energy savings. Therefore, optimization of drying processes continues to be a critical area of research. Furthermore, within the food industry, material is routinely dried for preservation and safety, ease of processing, product aesthetics, and consumer taste appeal; therefore, much attention has been devoted to the experimental determination of drying properties (Mujumdar, 1997). Further, drying of the productresulted in several changes in its physical properties. For example, most constituents of food materials (excluding water) have densities greater than water (1 g/cm^3); hence, as the water is removed during drying, the solid density of the product is increases (Karathanos et al., 1996).

Although some of the moisture in the product was lost by evaporation, the water activity was still high in the extruded products (all products had water activity more than 0.89), which offers a conducive environment for the growth of microorganisms. And hence, to provide the adequate self-stability, the drying of extruded product for few hours is necessary to produce a low moisture, low water activity product to give it shelf stability.

Table 3.2 Initial, at a_w (0.75) and final moisture content of extrudates, initial and final water activity and drying time to reach moisture content of 18% (db)

Run	Extrudate moisture content at 0 min (% db)	Extrudate a_w at 0 min	Drying time at a_w 0.75 (min)	Moisture content at a_w 0.75 (% db)	Drying time to reach 18% (db) (min)	Extrudate a_w at 18% (db)
1	44.70	0.930	148	23.6	225	0.682
2	31.99	0.928	107	20.1	120	0.699
3	45.39	0.942	145	22.4	198	0.713
4	41.66	0.936	115	22.8	165	0.632
5	45.39	0.933	88	22.1	180	0.599
6	49.00	0.912	120	21.9	270	0.639
7	35.65	0.908	95	22.8	120	0.612
8	45.58	0.933	113	25.5	195	0.627
9	39.68	0.913	83	22.7	135	0.520
10	36.02	0.927	105	20.5	150	0.701
11	44.55	0.929	135	20.2	195	0.715
12	38.70	0.925	107	21.5	150	0.618
13	47.04	0.931	95	24.3	165	0.575
14	45.71	0.926	155	25.7	285	0.681
15	40.67	0.910	135	20.7	195	0.629
16	45.67	0.927	93	24.0	195	0.594
17	45.52	0.926	92	26.1	195	0.613
18	49.21	0.936	130	22.8	210	0.636
19	39.80	0.906	80	21.4	135	0.512
20	35.43	0.899	115	21.1	180	0.589

Note: m.c. = Moisture content, a_w = Water activity, db = Dry basis.

The regression equation relating moisture content of the extruded products before drying to product variables is shown below (Eq. 3.8):

$$\mathbf{Y} = (0.36270 * F) + (0.42781 * O) + (0.38956 * P) - (0.031311 * W) + (1.96256E\text{-}004 * F * O) + (9.29095E\text{-}004 * F * P) + (4.40846E\text{-}003 * F * W) - (3.19274E\text{-}003 * O * P) + (8.51593E\text{-}003 * O * W) + (2.41482E\text{-}003 * P * W)$$

………... (3.8)

where: F for percentage finger millet flour content**;**

O for percentage oat flour content**;**

P for percentage potato starch content**;**

W for percentage whey protein isolate content.

The value of R^2 is 0.7899 and mean standard error is 0.15 for the fitted model.

3.3.2 Drying time to reach water activity of 0.75

Based on experimental drying conditions and the removal of moisture, drying time required to achieve the water activity of 0.75 were determined, as also listed in Table 3.2. The longest drying time was taken by Run 1 which had a formulation with 10% protein content with the remaining ingredients representing 50% F, 15% O and 25% P resulting in a final moisture content of 23.6% on dry basis when the water activity of 0.75 was achieved. On the other hand, the shortest drying time was obtained in Run 19 which had feed formulation with 0 percent protein content, 70% F, 10% O and 20% P and the resulting post drying moisture content was 21.4% on dry basis when the target water activity of 0.75 was achieved.

Figure 3.2 shows the response surface plot of drying time when the extruded product's water activity reached 0.75 during the drying process. It can be clearly seen that with an increase in protein content, the drying time to reach a_w of 0.75 also increased.

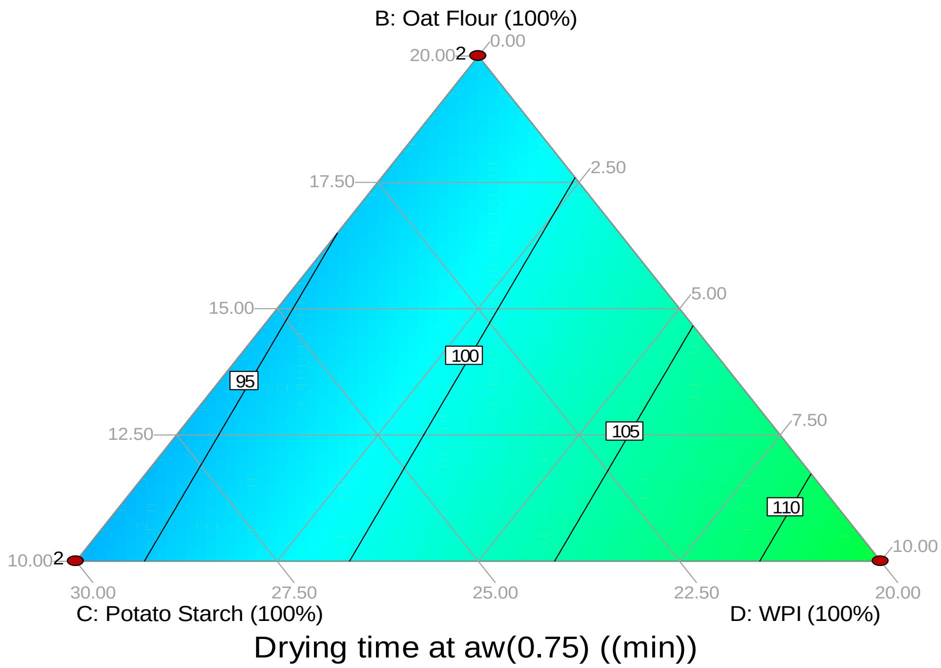

Figure 3.2 Response surface plot illustrates drying time when the water activity of extrudates reaches to 0.75 during the drying process at 60% finger millet flour proportion

This is supported by the fundamental concept given by Van Arsdel and Copley (1963) that during drying process, diffusion is the main mechanism of internal moisture migration. It occurs within the solid structure and/or within the capillaries, pores and small spaces saturated by vapor and may occur in different manners and under distinct drying conditions. And as the product dries, the rate of internal water migration decreases. Once the critical moisture content is attained, the surface is no longer saturated with water and drying rate begins to fall, starting the falling-rate period. From this moment and on, the drying rate is limited by the rate of water migration (or water diffusion) from inside the solid to its surface and, therefore, the product's nature (superficial area, constitutes orientation, type and concentration of solutes) play the most significant role (Barbosa-Canovas and Vega, 1996). The main driving force of drying is the free moisture content of the sample - higher moisture content generally resulting in longer drying times. However, the pre-drying structure and composition also play a role in the moisture diffusion process. Protein and other macromolecules are largely responsible for the diffusion resistance and a higher level of these can be expected to increase the drying time.

The extruded product's drying behavior is affected by the initial moisture content of the product (at 0 min). Holay and Harper (1982) mentioned that the moisture increases the mobility of proteins and potentially increases cross-linking and water absorption. Moreover, the results showed that because of differences in protein and other macromolecules present, the products also had different moisture contents in the dried to reach the 0.75 a_w, which is an important processing factor to the industry. Figure 3.3 is the response surface plot of product's moisture content at a 0.75 water activity of extrudates during the drying process. The trend shows that the increasing of protein content from 0 to 5% of the total formulation resulted in a product with a higher final moisture content at a_w of 0.75; however, a further increase from 5% to 10% of the total formulation reduced associated moisture content in the product at a_w 0.75.

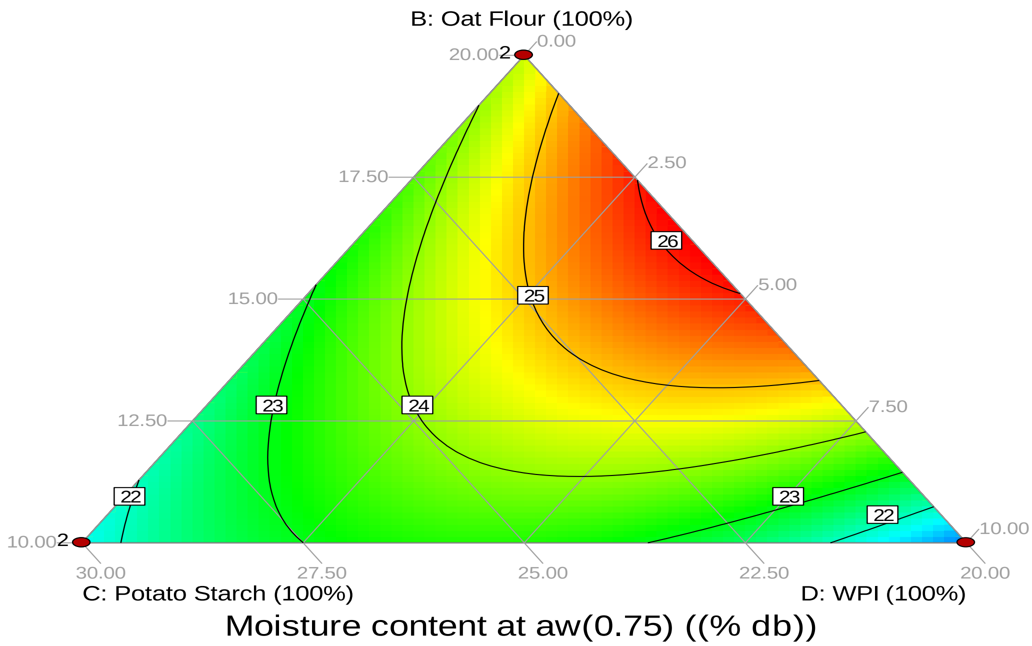

Figure 3.3 Response surface plot illustrates product's moisture content when the water activity of extrudates reaches to 0.75 during the drying process at 60% finger millet flour proportion

ANOVA for moisture content and drying time to reach the water activity of 0.75 is shown in Table 3.3. Total model gave significant correlations between experimental and prediction value both for the time and moisture content ($p<0.05$). All variables (finger millet flour content (F), oat flour content (O), potato starch content (P) and whey protein isolate content (W) significantly affected the drying time and moisture content in linear and quadratic forms, respectively. All the individual variables influenced the drying time. Moreover, the interaction between F-O, F-W, O-W and P-W were significant with respect to the extruded product's moisture content at 0.75 a_w.

Table 3.3 ANOVA for the condition when the water activity of the sample reach 0.75

Source	**Drying time at a_w 0.75**		**Moisture content at a_w 0.75**	
	df	**SOS**	**df**	**SOS**
Model	**3**	**5898.77**	**9**	**56.36**
Residual	**16**	**3666.43**	**10**	**5.53**
R^2	**0.6167****		**0.9106****	
Standard Error	**3.7**		**0.5**	

***p<0.05; **P<0.01; ns=not significant**

3.3.3 Moisture Ratio (MR) Modeling

Design-Expert software of version 9.0.4 was used to make the ANOVA and the predicted equation for moisture ratio. Basically the effect of four individual variables (finger millet flour content, oat flour content, potato starch content and whey protein isolate content) on the moisture ratio of the sample at different drying times (0, 15, 30, 45, 60, 75, 90 min) was studied. This procedure is slightly different from the conventional drying model which is generally based on a diffusion model. However, the concept is very similar in terms of being able to model moisture loss with respect to time.

Tables 3.4 summarizes the results for the moisture ratio which was significantly affected by F, O, P and W content at linear level. Table 3.5 summarized the model equations of MR in terms of actual factors at different drying time.

Table 3.4 Moisture ratio for each run at different drying times (starting from 0 to 105 min)

Run	Moisture ratio (MR)							
	0 min	15 min	30 min	45 min	60 min	75 min	90 min	105 min
1	1	0.87	0.79	0.74	0.68	0.63	0.60	0.55
2	1	0.84	0.75	0.68	0.59	0.55	0.50	0.48
3	1	0.89	0.81	0.73	0.67	0.61	0.56	0.52
4	1	0.82	0.75	0.71	0.64	0.58	0.53	0.49
5	1	0.86	0.75	0.66	0.61	0.55	0.50	0.46
6	1	0.91	0.84	0.78	0.73	0.69	0.66	0.61
7	1	0.83	0.72	0.61	0.56	0.50	0.45	0.39
8	1	0.88	0.79	0.72	0.65	0.6	0.55	0.51
9	1	0.88	0.77	0.70	0.61	0.55	0.49	0.44
10	1	0.92	0.85	0.78	0.71	0.66	0.59	0.54
11	1	0.89	0.81	0.73	0.66	0.61	0.57	0.53
12	1	0.80	0.72	0.65	0.60	0.55	0.50	0.47
13	1	0.87	0.80	0.72	0.66	0.59	0.53	0.46
14	1	0.89	0.81	0.76	0.72	0.68	0.64	0.60
15	1	0.85	0.78	0.71	0.66	0.61	0.57	0.52
16	1	0.90	0.84	0.76	0.69	0.63	0.58	0.53
17	1	0.83	0.73	0.68	0.59	0.56	0.51	0.47
18	1	0.87	0.77	0.69	0.63	0.58	0.54	0.50
19	1	0.83	0.73	0.65	0.57	0.51	0.46	0.44
20	1	0.86	0.80	0.74	0.68	0.63	0.59	0.57

Table 3.5 Regression equations for dried extrudate's moisture ratio at different drying time

Drying time (min)	Final Equation of Moisture Ratio in Terms of Actual Factors
0	$\mathbf{Y_{MR}}$ = (0.010000 * F) + (1.00000E-002 * O) + (0.010000 * P) + (1.00000E-002 * W)
15	$\mathbf{Y_{MR}}$ = (8.11624E-003 * F) + (0.011191 * O) + (7.96404E-003 * P) + (0.010704 * W)
30	$\mathbf{Y_{MR}}$ = (7.06616E-003 * F) + (0.011083 * O) + (6.98336E-003 * P) + (0.010994 * W)
45	$\mathbf{Y_{MR}}$ = (6.07910E-003 * F) + (0.010577 * O) + (6.51386E-003 * P) + (0.012216 * W)
60	$\mathbf{Y_{MR}}$ = (5.15373E-003 * F) + (9.87852E-003 * O) + (6.34242E-003 * P) + (0.012786 * W)
75	$\mathbf{Y_{MR}}$ = (4.33555E-003 * F) + (9.71854E-003 * O) + (6.0829E-003 * P) + (0.013484 * W)
90	$\mathbf{Y_{MR}}$ = (3.61723E-003 * F) + (9.14662E-003 * O) + (6.00098E-003 * P) + (0.014452 * W)
105	$\mathbf{Y_{MR}}$ = (3.34415E-003 * F) + (8.37304E-003 * O) + (5.52868E-003 * P) + (0.013677 * W)

ANOVA of the moisture content and water activity (a_w) of the extruded products at different drying time are listed in Table 3.6 and Table 3.7, respectively. The lack of fit was not significant indicating it to be a good model with the high — Pred R-Squared 0.92. The results showed that the finger millet flour content, oat flour content, potato starch content and whey protein isolate content significantly influenced the extrudate's moisture content and water activity during the drying process. With the proceeding of drying time, protein content affected a_w more significantly that can be seen for the drying time at 90 and 105 minutes.

Table 3.6 ANOVA for moisture content of the sample at different drying times

	0 min	15 min	30 min	45 min	60 min	75 min	90 min	105 min
Model	-	**	**	**	**	***	***	***
F	-	**	**	**	**	***	***	***
O	-	**	**	**	**	***	***	***
P	-	**	**	**	**	***	***	***
W	-	**	**	**	**	***	***	***
Lack of fit	-	NS	NS	NS	NS	NS	NS	NS

p≥0.10: Not significant (NS); *: 0.05≤p<0.10; **: 0.01≤p<0.05; ***: p<0.01; - : Not applicable.
F: Finger millet flour content, O: Oat flour content, P: Potato starch content, W: Whey protein isolate content

Table 3.7 ANOVA for water activity (a_w) of the sample at different drying times

	0 min	15 min	30 min	45 min	60 min	75 min	90 min	105 min
Model	***	**	**	**	**	***	***	**
F	***	**	**	**	**	***	***	**
O	***	**	**	**	**	***	***	**
P	***	**	**	**	**	***	***	**
W	***	**	**	**	**	***	***	**
Lack of fit	NS	NS	NS	NS	NS	NS	NS	NS

p≥0.10: Not significant (NS); *: 0.05≤p<0.10; **: 0.01≤p<0.05; ***: p<0.01.
F: Finger millet flour content, O: Oat flour content, P: Potato starch content, W: Whey protein isolate content

Figure 3.4 shows the general trends of moisture ratio vs time for the different formulations while Figure 3.5 the detailed moisture ratio vs time for a specific test run. Microsoft Excel was used to find the predicted moisture ratio for the drying process. Figure 3.6 shows the comparison of model predicted MR with the actual value of MR at middle point (50% F, 20% O, 30% P and 0% W) for all test runs. MR decreased with the increasing of drying time, and the predicted MR is very close to the actual MR value. The R^2 value was higher than 0.95. The points are also well distributed around the diagonal line except at the high end. The slope coefficient was 0.9978 indicating almost perfect fit within the overall range of experiments.

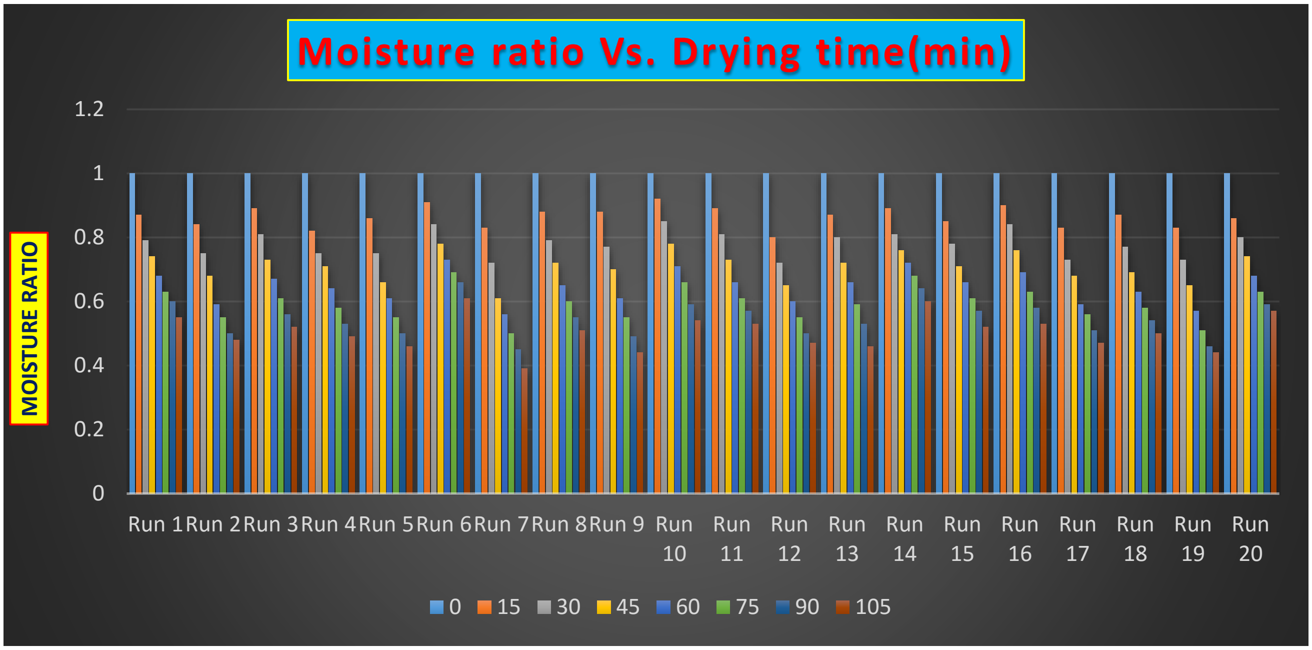

Figure 3.4 Graphical representation of Table 3.3 (MR vs. drying time [min] for all test run)

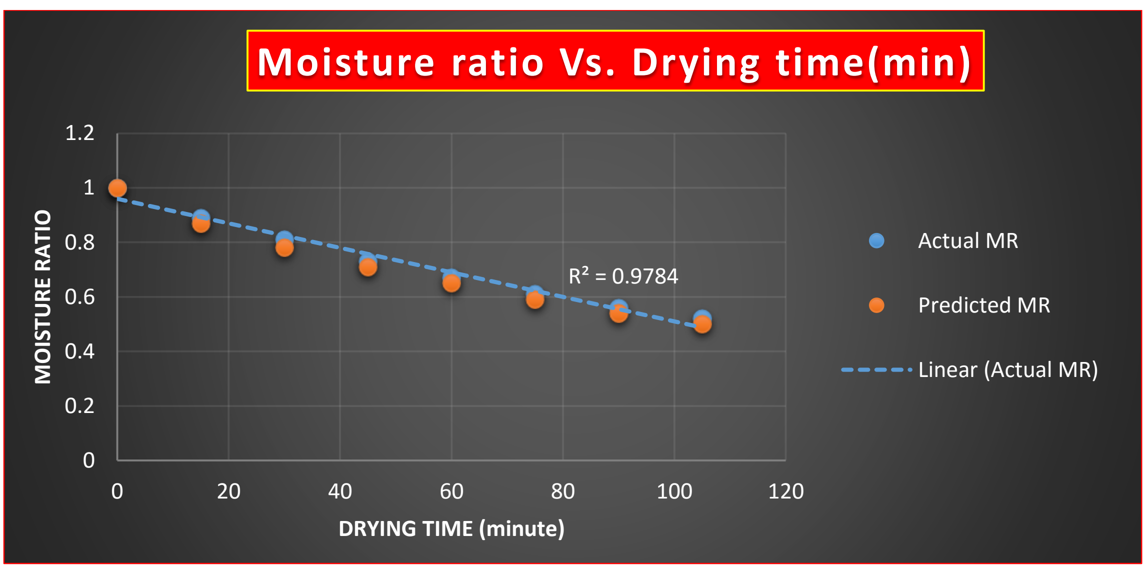

Figure 3.5 Comparison of model predicted and actual Moisture Ratio versus drying time (minute) for Run 3

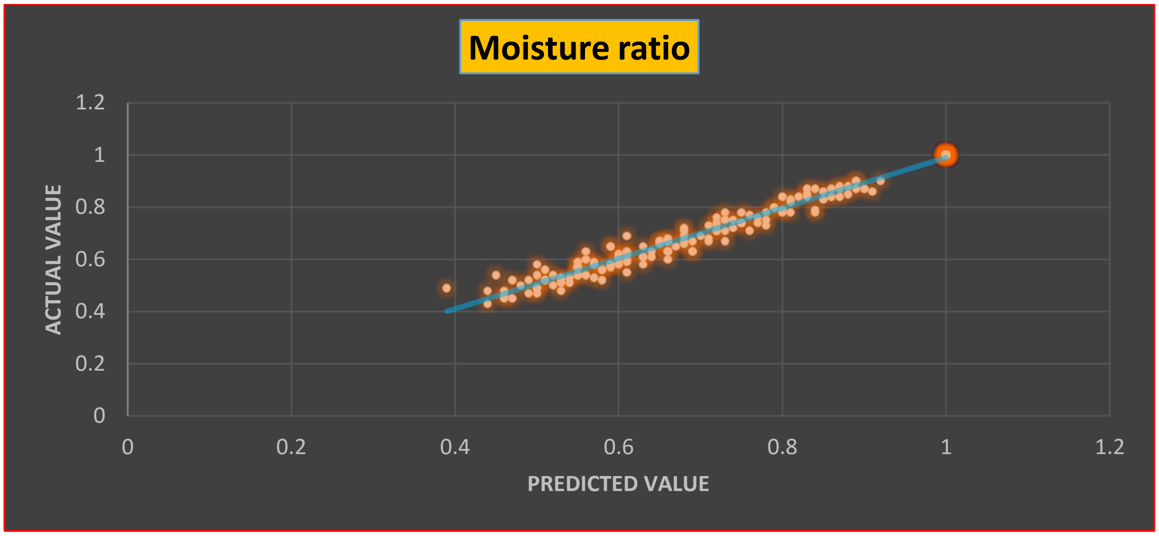

Figure 3.6 Comparison of model predicted moisture ratio with its actual value for all runs

3.3.4 Physical characteristics

The experimental arrangements (test run number) and data on the physical properties of breaking stress (BS), bulk density (BD), Expansion ratio (ER), rehydration rate (RR) and color (L*, a*, b* values) of extruded products are shown in Table 3.8. The table also indicates the approximate proximate composition of protein content (on wet basis) of the product obtained after the extrusion process. Second-order polynomial regression equations were established by considering significant factors on the basis of t (t-test) > 2.5 at probability level $0.01 <= p < 0.05$ and coefficients obtained are presented. The established equations show empirical relationship between physical properties (BS, BD, ER, RR and color) and actual values of independent variables of finger millet flour content (F), oat flour content (O), potato starch content (P) and whey protein isolate content (W). An analysis of variance (ANOVA) was performed to analyze the impacts of independent variables of finger millet flour, oat flour, potato starch and W on the physical properties of BS, BD, ER, RR and the color parameters of dried extruded product.

Table 3.8 Physical properties of the dried extruded products (mean values plus standard deviation in parenthesis)

Run	L* value	a* value	b* value	Bulk density (g/ml)	Rehydration ratio (%)	Expansion ratio	Breaking stress (N/mm^2)	Protein content (g/ 100g)
1	26.16 (1.25)	4.05 (0.62)	4.09 (1.33)	0.48 (0.02)	73.90 (4.09)	1.89 (0.12)	0.16 (0.02)	18.3 (1.2)
2	24.24 (1.75)	2.95 (0.12)	1.44 (0.76)	0.51 (0.01)	80.79 (15.22)	1.76 (0.18)	0.52 (0.28)	7.92 (0.78)
3	26.03 (6.40)	3.18 (1.45)	1.04 (3.40)	0.46 (0.02)	57.05 (7.74)	1.90 (0.05)	0.43 (0.09)	7.93 (0.77)
4	23.85 (1.99)	4.29 (0.99)	1.54 (3.23)	0.56 (0.03)	118.28 (12.93)	1.79 (0.16)	0.25 (0.05)	6.4 (0.98)
5	21.49 (2.64)	4.06 (1.03)	2.27 (1.62)	0.45 (0.02)	156.04 (13.21)	1.77 (0.04)	0.30 (0.08)	7.33 (0.69)
6	25.32 (0.79)	3.75 (1.76)	2.52 (2.86)	0.51 (0.01)	167.39 (16.94)	1.75 (0.04)	0.07 (0.03)	17.5 (0.99)
7	20.99 (1.96)	4.06 (0.69)	2.66 (1.79)	0.46 (0.03)	87.84 (13.91)	1.67 (0.20)	0.33 (0.09)	9.8 (0.54)
8	18.47 (1.45)	5.29 (0.92)	4.06 (0.66)	0.42 (0.03)	118.43 (26.47)	1.91 (0.08)	0.41 (0.04)	11.4 (0.35)
9	26.56 (2.03)	5.16 (0.97)	4.99 (2.70)	0.48 (0.02)	132.16 (5.66)	1.69 (0.04)	0.29 (0.07)	13.4 (0.44)
10	19.08 (1.98)	4.97 (0.81)	3.86 (1.98)	0.48 (0.03)	135.30 (20.3)	1.76 (0.15)	0.33 (0.04)	9.48 (0.62)
11	22.05 (5.44)	5.39 (0.67)	4.55 (3.09)	0.49 (0.02)	111.01 (21.25)	1.85 (0.07)	0.36 (0.05)	9.5 (0.70)
12	18.55 (2.74)	3.92 (1.31)	3.09 (1.54)	0.49 (0.02)	109.99 (18.07)	1.65 (0.13)	0.40 (0.12)	7.36 (0.81)
13	23.63 (2.52)	4.07 (1.47)	2.35 (2.30)	0.46 (0.01)	173.09 (20.97)	1.65 (0.07)	0.18 (0.03)	8.9 (0.35)
14	20.72 (4.04)	5.14 (0.54)	4.99 (1.14)	0.49 (0.03)	75.16 (22.13)	1.87 (0.08)	0.27 (0.04)	19.2 (0.81)
15	19.79 (1.48)	3.51 (0.32)	3.05 (1.57)	0.56 (0.02)	128.72 (17.52)	1.72 (0.05)	0.20 (0.07)	18.0 (0.77)
16	21.27 (5.06)	3.56 (2.21)	1.41 (1.50)	0.42 (0.03)	135.59 (24.71)	1.75 (0.04)	0.27 (0.05)	8.87 (0.46)
17	23.79 (6.21)	4.53 (1.38)	4.79 (1.93)	0.45 (0.03)	220.62 (14.57)	1.85 (0.13)	0.25 (0.07)	13.3 (0.25)
18	19.91 (0.48)	4.79 (0.42)	2.25 (3.13)	0.60 (0.02)	131.63 (5.61)	1.90 (0.10)	0.28 (0.07)	6.4 (0.54))
19	33.06 (1.61)	3.98 (0.40)	2.86 (2.99)	0.44 (0.02)	174.95 (27.76)	1.51 (0.05)	0.23 (0.05)	8.29 (0.35)
20	23.45 (3.01)	3.92 (0.47)	2.99 (3.16)	0.57 (0.01)	219.55 (25.13)	1.80 (0.05)	0.24 (0.07)	18.5 (0.75)

ANOVA study showed that finger millet flour content (F), oat flour content (O), potato starch content (P) and whey protein isolate content (W) were affected significantly ($0.01 \leq p < 0.05$) on the b* value, BD, RR and BS. All the four parameters showed the quadratic effect ($0.01 \leq p < 0.05$) to color (L*, a*, b*), BS and BD. While for the ER and RR, those components had showed the linear and special cubic effect respectively. Interactive effects of oat flour and potato starch were found their significant on RR, BS and b* value ($0.01 \leq p < 0.05$). While oat flour and W interaction significantly affected ($0.01 \leq p < 0.05$) on BD and RR. Also significant interactive effect ($0.01 \leq p < 0.05$) of potato starch and W was found on BD.

Various researchers have formulated different millet-based extruded snacks using millets like pearl millet, finger millet and foxtail (Almeida-Dominguez et al., 1993; Balasubramanian et al., 2012; Deshpande & Poshadri, 2011; Krishnan & Prabhasankar, 2010; Sawant et al., 2013; Seth & Rajamanickam, 2012; Singh et al., 2004; Yadav et al., 2014) with and without supplementation of cereals and pulses. Likewise a number of studies have also been carriedout for measuring the various physical characteristics such as expansion ratio, rehydration ratio, water solubility index, water absorption index, bulk density, true density, and porosity. In all studies, thes influence different extrusion process variables on these properties were determined. The influence of process variables on physical properties have been shown to be generally significant in most studies. Yu (2011) studied expansion ratio (ER), bulk density (BD), breaking stress (BS), water solubility index (WSI), rehydration ratio (RR) and color (L*, a* & b*) of corn flour blends with soy flour and soy protein isolate (SPI) using twin screw extruder. Meanwhile Forsido & Ramaswamy (2011) did a research on protein rich extruded products from tef, corn and soy protein isolate blends whereas they had measured the physical properties (color, ER, RR, WSI, BD and hardness) and its relation with extrusion process variables.

Table 3.9 ANOVA for physical characteristics of dried extrudates

Responses	Source	SOS	Df	Mean squares	F-value	P-value
	Regression	187.69	9	20.85	4.63	0.0126**
	Lack of fit	24.17	5	4.83	1.16	0.4382
L*	Pure error	20.88	5	4.18		
	Residual	45.05	10	4.50		
	Total	232.74	19			
	Regression	8.68	9	0.96	12.96	0.0002**
	Lack of fit	0.37	5	0.073	0.96	0.5164
a*	Pure error	0.38	5	0.076		
	Residual	0.74	10	0.074		
	Total	9.43	19			
	Regression	26.90	9	2.99	12.10	0.0003**
	Lack of fit	1.12	5	0.22	0.83	0.5772
b*	Pure error	1.35	5	0.27		
	Residual	2.47	10	0.25		
	Total	29.38	19			
	Regression	0.043	9	0.0048	10.12	0.0006**
	Lack of fit	0.0010	5	0.0002	0.27	0.9103
Bulk density	Pure error	0.0037	5	0.0007		
	Residual	0.0047	10	0.0005		
	Total	0.048	19			
	Regression	0.11	3	0.038	6.40	0.0047**
	Lack of fit	0.062	11	0.0057	0.88	0.6001
Expansion ratio	Pure error	0.032	5	0.0064		
	Residual	0.095	16	0.0059		
	Total	0.21	19			
	Regression	35265.85	13	2712.76	4.41	0.0394*
	Lack of fit	1262.51	1	1262.51	2.60	0.1679
Rehydration ratio	Pure error	2429.33	5	485.87		
	Residual	3691.85	6	615.31		
	Total	38957.70	19			
	Regression	0.18	9	0.020	8.75	0.0011**
	Lack of fit	0.0089	5	0.0018	0.63	0.6863
Breaking stress	Pure error	0.014	5	0.0028		
	Residual	0.023	10	0.0023		
	Total	0.20	19			

***0.01<P<0.05; **P≤0.01; ns=not significant**

Table 3.10 Analysis of Variance (ANOVA) for the individual variables and for the interactions between them during drying of extrudates (significance level p ≤ 0.05)

Source	L*	a*	b*	BD	RR	ER	BS
Model	0.0126	0.0002	0.0003	0.0006	0.0394	0.0047	0.0011
Linear Mixture	0.0646	0.0191	0.0004	0.0008	0.0278	0.0047	0.0012
AB	0.0397	0.0078	0.0036	0.3079	0.8882	-	0.1553
AC	0.0018	0.1427	0.5730	0.0945	0.4633	-	0.0381
AD	0.2121	0.0002	0.0004	0.0683	0.0568	-	0.1889
BC	0.0441	< 0.0001	0.0020	0.0249	0.0402	-	0.0025
BD	0.7027	< 0.0001	0.0001	0.0028	0.0212	-	0.3716
CD	0.9075	0.0011	0.0007	0.0023	0.0545	-	0.8277
ABC	-	-	-	-	0.3806	-	-
ABD	-	-	-	-	0.0664	-	-
ACD	-	-	-	-	0.1301	-	-
BCD	-	-	-	-	0.3571	-	-

***0.01<P<0.05; **P≤0.01; ns=not significant**

Table 3.11 Analysis of Variance (ANOVA) for the fit of experiment data to D-optimal mixture design (Dried extrudates)

Source	L*	a*	b*	BD	RR	ER	BS
R^2	0.8064*	0.9210**	0.9159**	0.9011**	0.9052*	0.5456**	0.8873**
Adj R-Squared	0.6322	0.8499	0.8402	0.8120	0.6999	0.4604	0.7859
Pred R-Squared	0.3395	0.6668	0.6426	0.6151	N/A	0.2957	0.6131
Adeq Precision	9.106	11.242	11.454	9.982	7.451	8.276	12.337

$^*0.01<P<0.05$; $^{**}P\leq0.01$; ns=not significant

I. Color

The color of dried extruded products (until the final moisture content left was 18% db) were measured using a Minolta Tristimulus Colorimeter (Minolta Corp., Ramsey, NJ, USA). The color parameters in terms of CIELAB L* (degree of lightness), a* (red/green) and b* (yellow/blue) values were obtained by software (SpectraMagic, Minolta Corp., Ramsey, NJ, USA). The main treatment effects due to changing finger millet flour (F), oat flour (O), potato starch (P) and W (W) levels on the color values (L*, a* and b*) are shown in Tables 3.8 - 3.11. The obtained results indicated that the L* values of dried extruded products varied between 18.5 and 33.1, a* values ranged from 2.95 to 5.39 and b* values varied from 1.04 to 4.99.

Color is one of the most vital attributes of any food product due to consumer acceptability and their buying decisions. Processing conditions during extrusion often lead to color change by nonenzymatic browning which normally results from Maillard reaction between proteins and reducing sugars (Berset, 1989). Several other reasons are known to affect the color change during extrusion cooking viz., caramelization, hydrolysis, and others, as well as a nonenzymatic reaction, such as the degradation of pigments (Camire et al., 1990). But Maillard reaction happened noticeably around 154 °C, significant browning of food did not occur until all surface water is vaporized, so browning is not seen in lower and intermediate process conditions.

(A) L* value

Figure 3.7 shows the contour graph obtained by fitting quadratic model to L* value. Analysis of variance (ANOVA) was used for the evaluation of quadratic model. The lack of fit for the fitted model was not significant demonstrating the adequacy of the model. L* gives information about the darkness - lightness characteristic of the product. Positive value (+) is an indicator of lightness while negative value (-) means the product is darker. There will be higher possibilities of extreme values going to be recorded at severe extrusion conditions mainly due to Maillard reaction which is evident at higher temperature and screw speed as the flours and externally added protein rich source have higher protein content and also high temperature combined with intermediate moisture favorably leads to non-enzymatic browning.

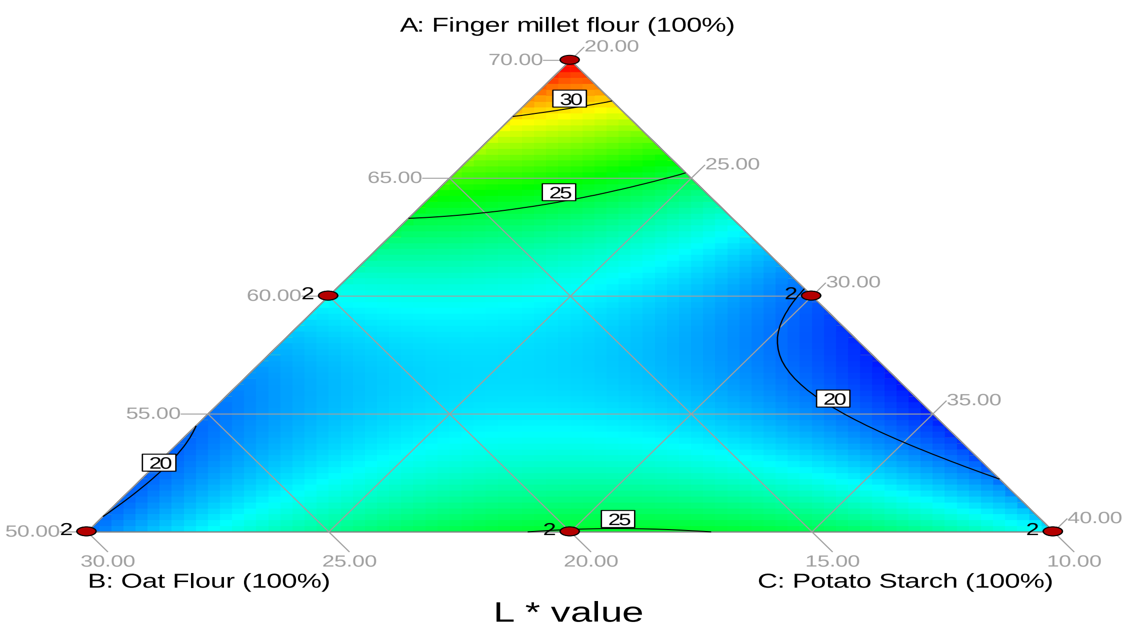

Figure 3.7 Effects of formulation on L* value for dried extrudates at 0% W proportion

There were F and P content showed their significant effect of linear terms on L* value. The ANOVA results (Table 3.9) also showed that L* was significantly ($p<0.05$) affected by the interaction between finger millet flour-oat flour, finger millet flour-potato starch and oat flour-potato starch.

The regression equation reflecting the relationship between L* value (Y_{L*}) and independent variables in terms of actual values is as follows; quadratic model was selected for L* value according to statistical significance (Design Expert 9.0.4).

$$\mathbf{Y_{L*}} = (1.60889 *F) + (0.345773 *O) + (2.51249 *P) + (3.10109 *W) - (0.0449476 *F *O) - (0.0783312 *F *P) - (0.0747004 *F *W) + (0.0413615 *O *P) - (0.0231873 *O *W) + (0.00726978 *P *W) \quad \text{………... (3.9)}$$

The R^2 is 0.8064 and mean standard error is 1.28 for the fitted model.

The interaction between oat flour-potato starch and potato starch–whey protein isolate showed positive quadratic regression coefficient showing a direct relationship between variables whereas the interaction between the finger millet flour-oat flour, oat flour–whey protein isolate as well as finger millet flour-potato starch were showed negative quadratic regression coefficient demonstrating the opposite.

Another reason, apart from the process variables, behind lower L* value might be due to low screw speed, constant for all the runs, which was 100 rpm in this study. Because in the study done by Hsieh et al. (1993) with an objective of to investigate the effects of screw speed, salt (0-3%) and sugar (0-8%) contents on the extrusion of rice flour using a co-rotating, fully intermeshing twin screw extruder, they found that raising of the screw speed from 200 to 300 rpm resulted in whiter and less green extrudates. Similar finding was reported by Chakraborty et al. (2014) during their study detecting an influence of extrusion conditions on the color of millet-legume extrudates using digital imagery. They observed L* registered a significant ($p<0.01$) increase with increase in screw speed. The reason behind explanation was that the higher screw speed leads to decrease in residence time of the melt inside the extruder ultimately leading to a lesser browning of product. And so we can achieve a higher L* value. Also Bhattacharya et al.

(1997) had found the identical findings with green gram-rice extrudates. So this could perhaps be explored further as one of the important parameters in future consideration. On contrary, Ilo et al. (1999) who studied the kinetics of color change concluded that change in color mainly depends on product temperature. Shear may cause the destruction of some carotenoid pigments in extrusion cooking (Marty and Berset, 1986). Increasing screw speed in extrusion cooking increase the shear stress in the active cooking zone, leading to higher product temperature and thus cause overheating of material. These conditions would favour browning reactions and thus results into the darkening of yield.

The model was significant with p = 0.0126 (<0.05). The fit of the model was expressed by the R-squared, which was found to be 0.81 indicating that over 80% of the variability of the response could be explained by the model. The adjusted R^2 of the model was found to be 0.63. The Adequate Precision value of 9.1 indicated inadequate signal indicating that this model should be used to navigate the design space.

(B) a* value

The negative value (-) for a* means the product shows red color attributes while the positive (+) value is a measures of product's greenness. The plot of a* value as influenced by process variables is presented in Figure 3.8. The linear terms of all the process variables had significant effect on a* value. Further, results of ANOVA also revealed that the value of a* was significantly affected (p<0.01) by the interaction between F-O, F-W, O-P, O-W and P-W. The fit of the model was expressed by the R-squared, which was found to be 0.92 indicating that over 90% of the variability of the response could be very well explained by the model. The lack of the fit for the fitted model was not significant demonstrating the adequacy of the model. The Adequate Precision value of 11.2 indicates inadequate signal indicating that this model should be used to navigate the design space.

The following regression equation shows the relationship between a* value (Y_{a*}) and independent variables in terms of actual values, moreover quadratic model was selected for a* value according to Design Expert 9.0.4.

Y_{a*} = (0.073026 * F) + (0.74135 * O) + (0.309543 * P) – (3.75151 * W) – (0.00811712 * F * O) – (0.00381546 * F * P) + (0.0409285 * F * W) – (0.0181053 * O * P) + (0.048336 * O * W) + (0.0355973 * P * W)

……….... (3.10)

The R^2 is 0.9210 (Table 3.11) and mean standard error is 0.16 for the fitted model.

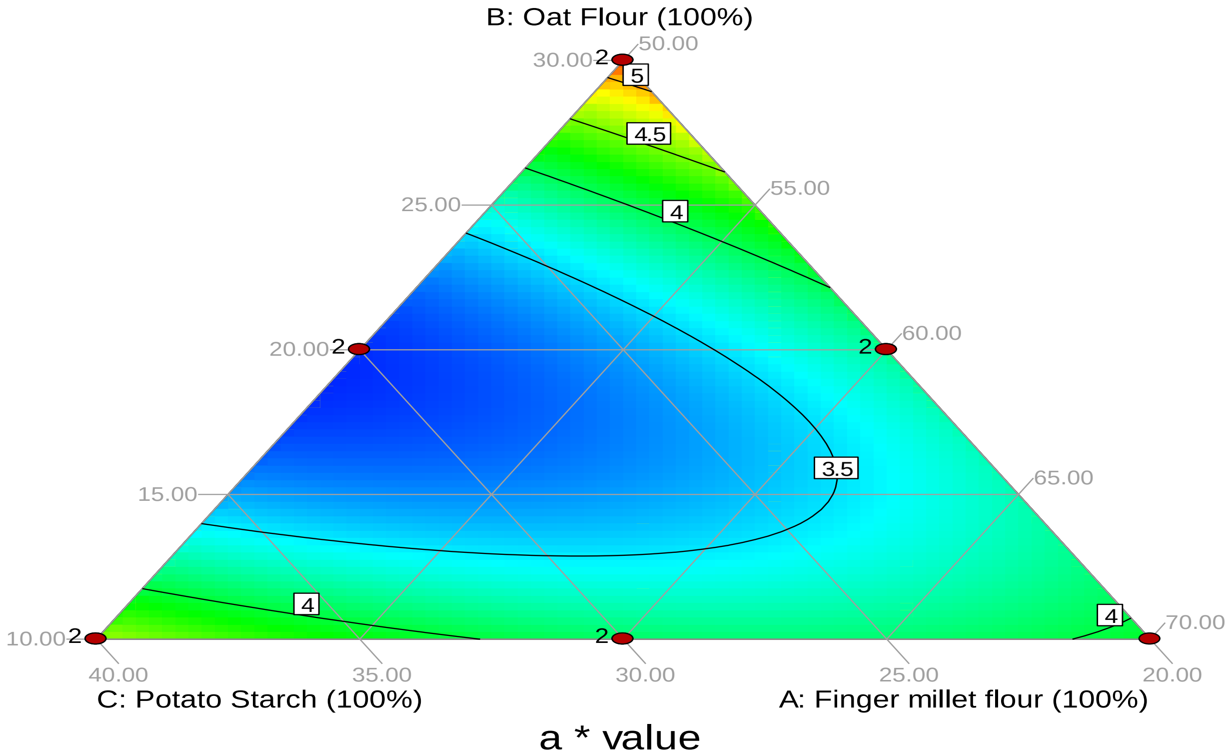

Figure 3.8 Effects of formulation on a* value for dried extrudates at 0% W proportion

The interaction between F-W, O-W and P-W showed the positive quadratic regression coefficient whereas the interaction between the F-O as well as F-P showed negative quadratic regression coefficient. Enhanced a* was observed in the dried extrudates with an increase in the oat flour meanwhile reduction in potato starch content in the feed. Higher a* means the color is traversing through the brown region towards red; this can be attributed due to caramelization of sugar from the Maillard reaction. Generally that's why higher redness (a*) value has observe as the temperature increases.

(C) b* value

Another parameter of interest for color is b* value (its position between yellow and blue in the Hunter color space). The negative value (-) for b* means the product shows blue color attributes while the positive (+) value is a measures of product's yellowish color attribute. Figure 3.9 shows the contour graph of b* values (yellowness/blueness).

The R-squared was found to be 0.92 indicating again that over 90% of the variability of the response could be very well explained by the model and hence it has proved the model's fitness.

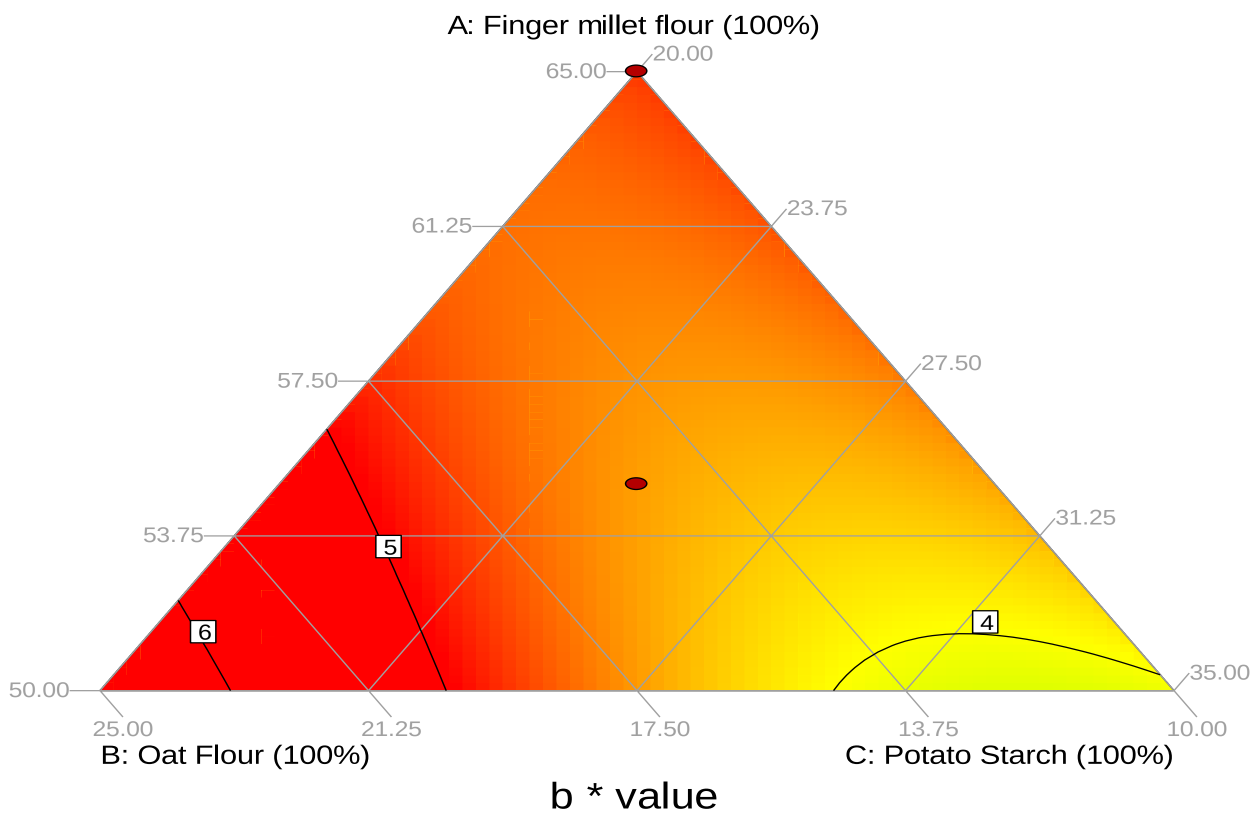

Figure 3.9 Effects of formulation on b* value for dried extrudates at 5% W proportion

The following regression equation shows the relationship between b* value (Y_{b*}) and independent variables in terms of actual values, moreover quadratic model was selected for b* value according to Design Expert 9.0.4.

$\mathbf{Y_{b*}}$ = (0.0589968 * F) + (1.19155 * O) – (0.0691365 * P) – (6.28696 * W) – (0.0168179 * F * O) + (0.00254609 * F * P) + (0.0677072 * F * W) – (0.0174639 * O * P) + (0.0821721 * O * W) + (0.0684804 * P * W)

……….. (3.11)

The R^2 is 0.9159 (Table 3.11) and mean standard error is 0.30 for the fitted model.

The linear terms of all the process variable had their significant effect ($p<0.01$) on b* value. Further, ANOVA results showed that the b* value was significantly affected ($p<0.01$) by the interaction between F-O, F-W, O-P, O-W and P-W. In addition, W as well as interaction between F-O and O-P showed the negative quadratic regression coefficient whereas the rest showed positive quadratic regression coefficient.

The results in general indicated that the rise in b* value could be mainly due to increase in oat flour and decrease in finger millet flour content. Likewise increase in oat flour and decrease in potato starch content also resulted in higher b* value. Baik et al. (1995) examined discoloration of dough for oriental noodle and found out that the color differences between wheat flour noodle dough was highly correlated with differences in starch (as measured by gelatinization, differential scanning calorimetry, or amylose-amylopectin parameters) or protein (as measured by dough mixing and bread making). On the other hand, the potential reason behind lower b* value could be the presence of salt content. Because Whistler and Daniel (1985) found that salt interfered with browning reactions such as caramelization and Maillard reactions, probably by lowering the water activity where maximum browning reaction occurs.

II. Rehydration ratio (RR)

Extruded products are generally rehydrated, at least partially, before its consumption e.g. breakfast cereals. That is the main reason behind measuring the ability of liquid absorption by the product. The special cubic model was found to be significant (Table 3.9) with p = 0.0394. Hence it has been used for ANOVA. The range found for the RR value was from 57.1 to 220.6. In addition, the value of RR was significantly ($p<0.05$) affected by all components of formulation (proportion of finger millet flour, oat flour, potato starch and whey protein isolate) and also by interactive effects of oat flour-potato starch as well as oat flour-whey protein isolate.

Figure 3.10 shows that mixtures containing lower concentration of potato starch in combination with higher amounts of finger millet flour and oat flour yielded high RR. Also the same findings were observed with higher whey protein isolate content with lower potato starch. The effects of the proportion of ingredients on RR were straightforward such as RR decreased with increasing potato starch content. Special cubic regression coefficient analysis showed that RR was positively related to each process variable while negatively related to interactive effect of O-P and O-W.

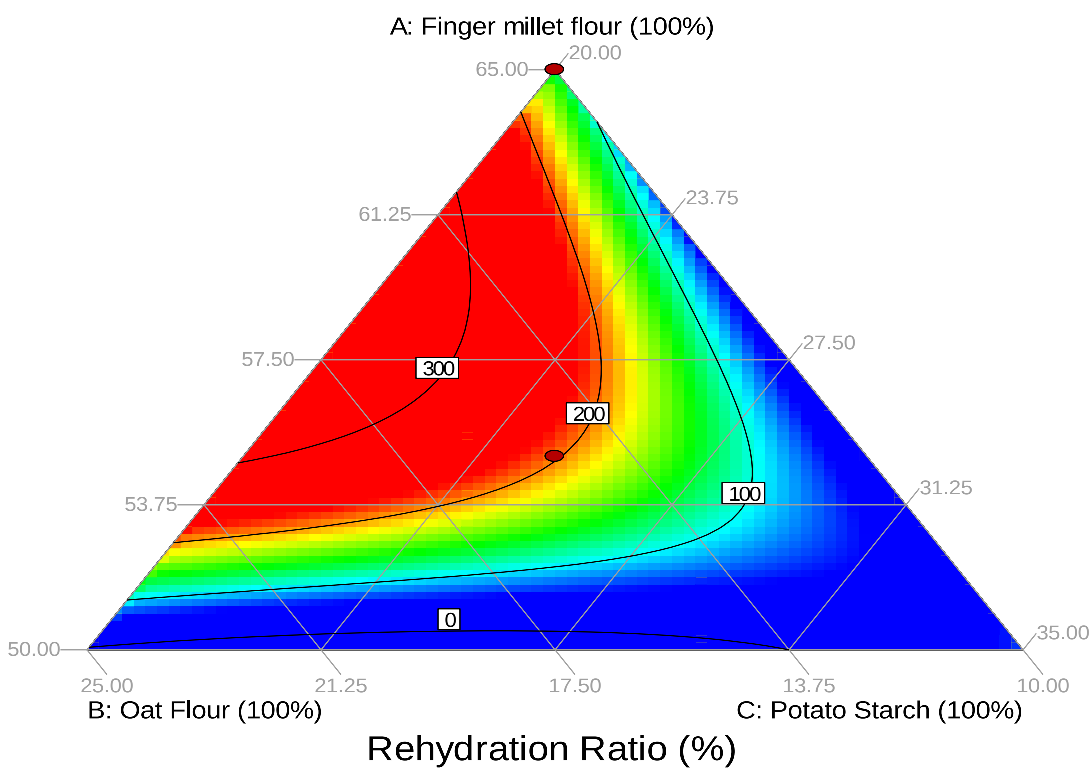

Figure 3.10 Effects of formulation on rehydration ratio at 5% W proportion

The fitted regression equation in actual values for RR is as following.

$$\mathbf{Y_{RR}} = (56.2119 * F) + (484.346 * O) + (224.306 * P) + (516.469 * W) - (10.5863 * F * O) - (5.49173 * F * P) - (9.17233 * F * W) - (27.1109 * O * P) - (54.701 * O * W) + (8.81371 * P * W) + (0.531013 * F * O * P) + (1.06211 * F * O * W) - (0.214173 * F * P * W) - (0.122809 * O * P * W) \quad \ldots\ldots\ldots\ldots (3.12)$$

The R-squared was found to be 0.9052 and mean standard error was 21.5 for the fitted model indicating that 90.5% of the variability of the response could be very well explained by the model. The lack of the fit for the fitted model was not significant demonstrating the adequacy of the model. The Adequate Precision value of 7.45 indicates inadequate signal tells that this model should be used to navigate the design space. It can be clearly seen, from two component mix effect between finger millet flour and W, that rehydration ratio of dried extrudate decreased with the increasing W content. The reason behind this was explained by Eliasson (1983) study on wheat-starch gluten mixtures which reported that the lack of protein in raw materials could make starch gelatinization easier, since there is no material that can compete with starch in water absorption characteristic. The same trend was mentioned by Yagci and Gogus (2008) in a different context that protein content in feed decreases the starch molecular degradation, an increases in protein content with relative decrease in starch content may influence the extent of starch gelatinization during extrusion processing leading to a decrease in relative water absorption. This phenomenon may cause the decrease of rehydration rate of extrudate with the increase in whey protein isolate content in feed blends. Further, Gumul et al. (2015) stated in their research findings about the usability of residual oat flour (ROF) in the manufacture of extruded corn snacks. Hence they have mentioned that it could be suggested that increase in the water binding ability was mainly caused by the addition of protein and dietary fiber contained in ROF. This is very similar to the trend seen in this study findings.

Moreover, extrusion alters several functional properties of starch which is mainly depending on the relation amylose-amylopectin as well as on the operational parameters of the process such as the raw-material moisture content, the barrel temperature, the screw speed and geometry (Harper, 1981). Extrusion of starchy food results in gelatinization, partial or complete destruction of the crystalline structure and molecular fragmentation of starch polymers, as well as protein denaturation, and formation of complexes between starch and lipids, and between protein and lipids (Colonna & Mercier, 1983). Moisture content usually acts as a plasticizer during extrusion cooking. Hence higher moisture content during extrusion reduces the degradation of starch granules and this results in an increased capacity for water absorption. In contrast, increasing feed moisture content may lead to retain high moisture content inside the extruded products and consequently decrease the rehydration rate. However, low moisture content reduces the water absorption capacity mostly due to an increase in starch degradation during extrusion.

Another perspective to be considered is high processing temperature probably creates more open spaces and air cells in the product structure due to high temperature generates high thermal energy, which increases the level of superheated steam during extrusion processing. This may impart to imbibe more water when rehydrating the extruded products. Thus rehydration rate of extrudate increases with the increasing of extrusion processing temperature.

III. Expansion ratio (ER)

Figure 3.11 shows the contour graph obtained by fitting linear model to ER value. Analysis of variance (ANOVA) was used for the interpretation of linear model. The lack of fit for the fitted model was not significant demonstrating the model's adequacy. Expansion of the extrudates is primarily related with the product's crispiness, water absorption, water solubility, and crunchiness. Expansion ratio gives an indication of the puffing property of the formulation undergone through extrusion cooking. When the extrusion process is carried out at temperatures above 100°C, the moisture present is superheated inside the extrusion barrel due to internal high temperature and high-pressure conditions (Park et al. 1993). As the product exits the die nozzle, the moisture flash-evaporates instantaneously due to the pressure drop. As a result, the extruded product is expanded, and the characteristic texture of the extrudate is formed with a porous structure. But the previous studies disclosed that larger expansion ratio promotes increase in porosity and further it may results in softer texture compared with the product which has low expansion ratio (Yu et al., 2012).

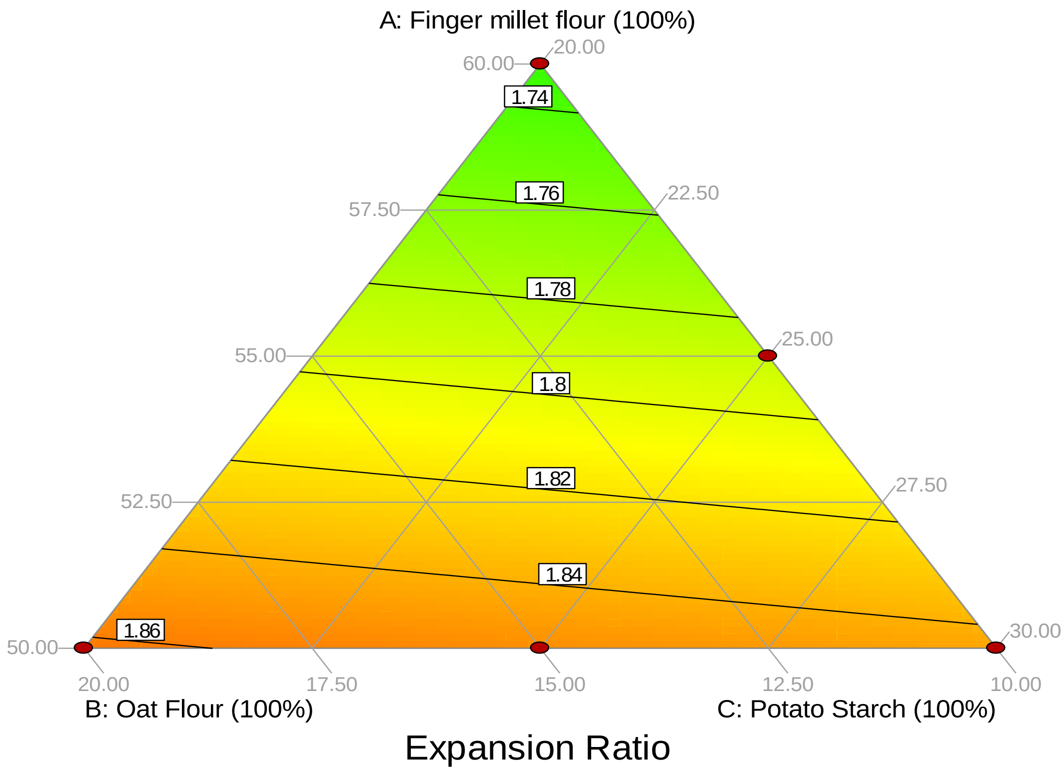

Figure 3.11 Effects of formulation on ER value for dried extrudates at 10% W proportion

The linear terms of all the process variables had showed significant effect ($p<0.01$) on ER values. The regression equation indicating the relationship between ER value (Y_{ER}) and independent variables in terms of actual values is as follows, linear model was selected for ER value according to Design Expert 9.0.4.

$$\mathbf{Y_{ER}} = (0.0121742 * F) + (0.0253801 * O) + (0.0235985 * P) + (0.0274227 * W) \quad \text{………... (3.13)}$$

The R^2 is 0.5456 and mean standard error is 0.02 for the fitted model. There was no significant difference in the ER of the 20 different formulations (Table 3.8). This shows that the finger millet flour based formulation has a comparable potential with that of corn for the preparation of puffed products. The model was significant with p = 0.0047. The fit of the model was expressed by the R-squared, which was found to be 0.5456 indicating that 54.6% (not very high but significant) of the variability of the response could be explained by the model. The

“Adequate Precision” measures the signal to noise ratio. A ratio greater than 4 is desirable. The value of Adequate Precision for ER was found to be 8.28 and hence it means this model can be used to navigate the design space.

Obtained results clearly explained that each variable showed a positive linear regression coefficient. Further analysis revealed that the value of expansion ratio decreases with higher finger millet flour proportion in the mixture. The trend also showed the higher ER value attained with an increases in oat flour content. Likewise the same effect was shown by potato starch proportion as the value of ER increases with the rise in potato starch content.

It appears that the observed increase in extrudate volume was caused by the addition of soluble fiber, which even in small amounts has been shown to improve the expansion of cereal extrudates (Kaur et al., 1999). Higher expansion is primarily considered to be dependent on starch content in the raw material. While the reason explaining decreased in expansion ratio could be because of high level of finger millet flour, which is rich in dietary fiber. Apart from that, the previous studies demonstrated effects of protein on expansion through their ability to effect water distribution in the matrix and through their macro molecular structure and confirmation. In addition feed moisture content also plays a significant role on the expansion ratio as study showed the value of expansion ratio decreases with increases in feed moisture content. Because increased feed moisture content during extrusion would change the amylopectin molecular structure of the starch-based material, reducing the melt elasticity that decreases the expansion ratio.

Although higher temperature leads to greater vapor pressure and increased driving force for expansion, it also can lead to a decrease in melt viscosity and, consequently, a greater degree of extrudate collapse (Cha et al., 2001). Other extrusion studies have noted an increase in expansion with temperature to a specific optimum at 125–160°C, with further temperature increases causing either a decrease or no change, depending on the type of starch and moisture content (Chinnaswamy and Hanna 1988; Chinnaswamy 1993; Bhattacharya and Prakash 1994; Cha et al 2001; Moraru and Kokini 2003).

IV. Breaking stress (BS)

Figure 3.12 shows the contour graph of BS as influenced by proportion of ingredients. The BS of extrudates were significantly ($p<0.01$) affected by proportion of finger millet flour, oat flour, potato starch, W, and interaction effects including oat flour-potato starch. Moreover it was also affected significantly ($0.01 \leq p < 0.05$) by the interaction effect of finger millet flour-potato starch. The fitted regression equation for BS in actual values is shown below:

$$Y_{BS} = -(0.00217548 * F) + (0.0178972 * O) - (0.0532416 * P) - (0.100184 * W) - (0.000658424 * F * O) + (0.00100314 * F * P) + (0.00178005 * F * W) + (0.00162593 * O * P) + (0.00124384 * O * W) - (0.000306956 * P * W) \quad \text{………... (3.14)}$$

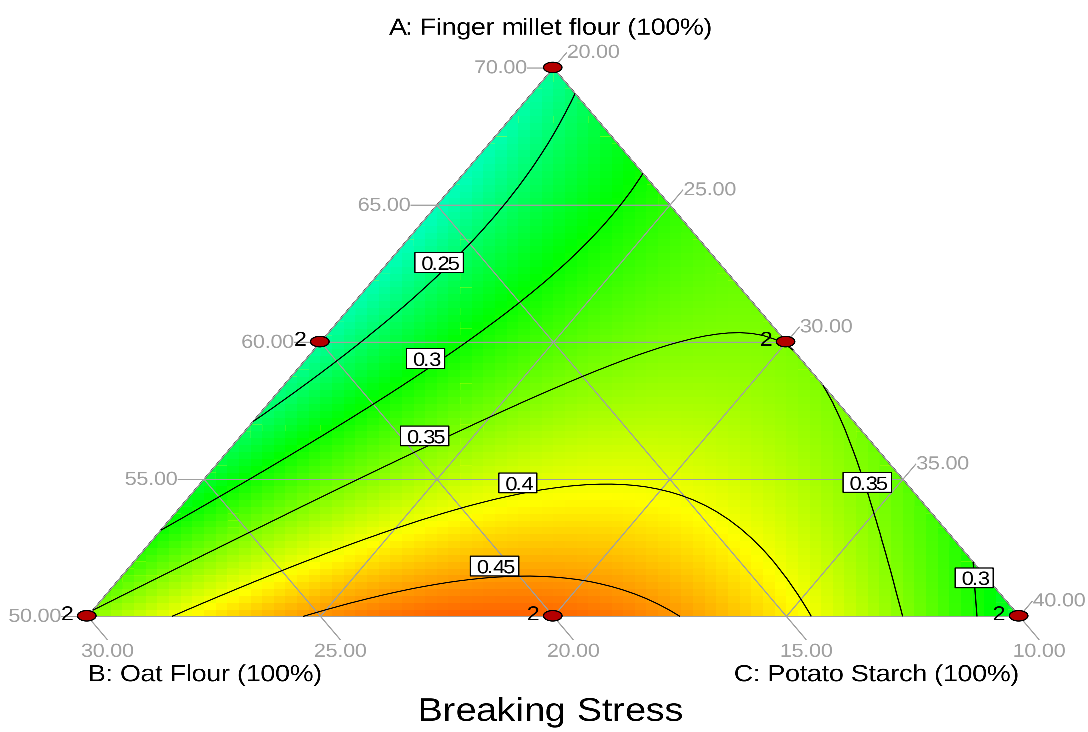

Figure 3.12 Effects of formulation on BS value for dried extrudates at 0% W proportion

The R^2 is 0.8873 and mean standard error is 0.03 for the fitted model. The 0.8873 R-squared value indicates that 88.7% of the variability of the response could be very well explained by the model and hence the model is fitted. The lack of the fit for the fitted model was not significant demonstrating the adequacy of the model. The Adequate Precision value of 12.3 indicates inadequate signal indicating that this model should be used to navigate the design space. The quadratic model was found to be significant (Table 3.11) with $p = 0.0011$. Hence it has been used for ANOVA. The range for the BS value found was from 0.07 to 0.52. Figure 3.12 exhibits mixtures containing higher concentration of potato starch in combination with lower amounts of oat flour and lower finger millet flour yielded lower BS. The effects of the proportion of ingredients on BS were clearly understood as the mixture containing lower potato starch proportion gives higher BS. Quadratic regression coefficient analysis disclosed that BS was positively related to each process variable (except W; negative quadratic regression coefficient) as well as the interactive effect of F-P and O-P.

Generally, addition of fiber to an extruded product results in increased product density and hardness. Great differences have been observed with increasing amounts of fiber as a result of its effect on air cell wall thickness (Forsido & Ramaswamy, 2011). Meanwhile Devi et al. (2011) reported that finger millet flour is a rich source of dietary fiber. It varied according to variety from 7.00 to 21.2 of its composition. In addition to that oat flour is also considered to be superior source of dietary fiber. This might have been contributed to the increased hardness of extrudates with increasing levels of finger millet flour and oat flour.

When starch undergoes extrusion-cooked, expansion is dependent on the formation of a starch matrix that entraps the water vapor resulting in the formation of bubbles. As mentioned before, high moisture can change the molecular structure of amylopectin reducing the elastic viscosity and thus decreasing the expansion (Ding et al., 2005; Guy and Horne, 1988). Hsieh et al. (1990), reported a relationship between the expansion ratio and shear force in extruded corn products in which products with the highest expansion index values were also those with the lowest shear force values. The reason given was the extrudates with the highest expansion index values formed cells with thin walls, resulting in low shear force values. Taverna et al. (2012) mentioned that it’s reasonable to suggest that the addition of flour containing high content of protein and lipids might have affected the character of the starch matrix (i.e., the viscoelastic properties of molten extrudate) so that it no longer holds water vapor, resulting in higher break strength. Biliaderis (2003) proposed that texture in starch based products becomes harder due to rapid amylose crystallization during cooling and slow amylopectin crystallization during storage.

V. Bulk density (BD)

BD is defined as the mass of a particulate material divided by the total volume occupied by them. In case of extruded products, the total volume includes particle volume, inter-particle void volume and internal pore volume. Importance given for measuring the bulk density due to its impact on container fill and hence directly plays a role in a storage and transportation (Mercier et al., 1989). Further it also depends on the size, shape and the extent of expansion during extrusion (Kurt et al., 2009).

Figure 3.13 shows the effect of formulation on BD value for dried extrudates at 0% W proportion and Figure 3.14 shows the two parameter interaction effects. The experimental values of BD of extrudates under different designed compositions were presented in Table 3.8. The values were ranged from 0.42 – 0.60 g/ml for the dried extrudates. The quadratic model was found to be significant with $p = 0.0006$. The value of BD was significantly ($p<0.01$) affected by the type of formulation (proportion of finger millet flour, oat flour, potato starch and W) and also by the interactive effects of O-W as well as P-W. In addition, the interaction between oat flour-potato starch had also showed their impact significantly ($0.01 \leq p < 0.05$).

The fitted regression equation in actual values for BD is given below:

$$Y_{BD} = (0.00632606 * F) + (0.0196784 * O) + (0.0266937 * P) + (0.156262 * W) – (0.000208879 * F * O) – (0.000352192 * F * P) – (0.00117039 * F * W) – (0.000484322 * O * P) – (0.00236805 * O * W) – (0.00253552 * P * W) \qquad \text{………... (3.15)}$$

The value of mean standard error is 0.01 for the fitted model. The value of R-squared was found to be 0.9011. The lack of the fit for the fitted model was not significant demonstrating the adequacy of the model. The Adequate Precision value of 9.98 indicates inadequate signal meaning is that this model should be used to navigate the design space.

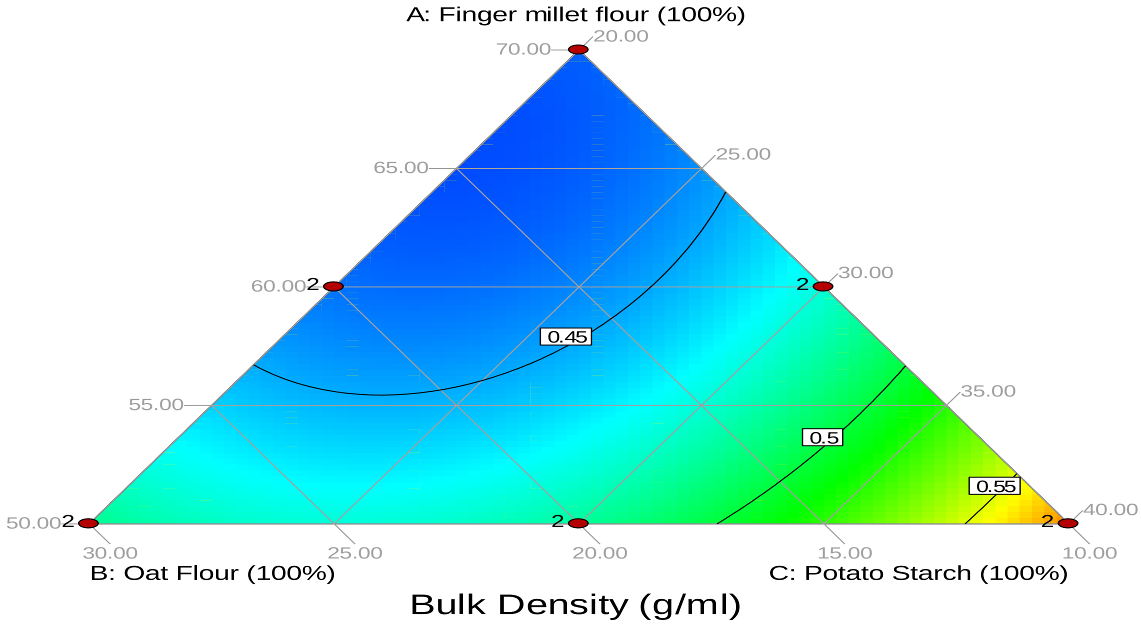

Figure 3.13 Effects of formulation on BD value for dried extrudates at 0% W proportion

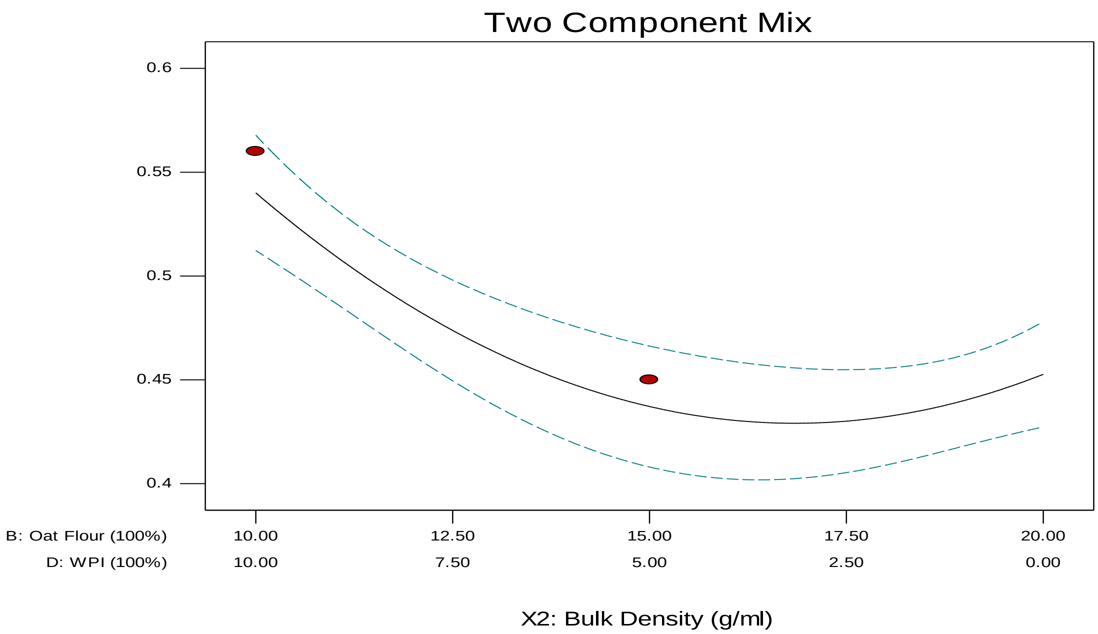

Figure 3.14 Interactive effects of two component mix (O-W) on BD value for dried extrudates at 55% finger millet flour and 25% potato starch proportion

The results indicated that each variable showed a positive quadratic regression coefficient. While in case of interactive effects of O-P, O-W and P-W displayed negative quadratic regression coefficient. Analysed data revealed about value of bulk density that decreases with increases in oat flour proportion in the mixture. As a further matter, the increasing trend showed in the BD value with an increases in finger millet flour content as well as potato starch content in the formulation. Likewise the same effect had shown by rise in W content as the value of BD increases.

Both ER and BD represent the extent of puffing of the extrudate. Therefore, it might be expected that these two properties would be negatively correlated, with higher ER contributing to lower BD (Yu, 2011). But Park et al. (1993) reported that this is not always the case. The reason could be that ER only considers the expansion in the radial direction, perpendicular to extrudate flow, whereas BD considers the expansion in all directions (Falcone and Phillips, 1988). In this study, a significant inverse relationship was found between ER and BD.

Among all components of oat flour, lipids and fibres have found to have the biggest influence during the extrusion, because they cause low expanded extrudates. Another reason for low expansion is the low quality of starch in oats, which contains small amount of amylopectin. Wicklund (1995) mentioned that low expansion and hard texture might also cause by the high fibre content of oat. Also similar finding was reported by several studies that increasing the amount of oat flour content decreased the expansion and increased hardness of the extrudates (Lue et al., 1991; Liu et al., 2000; Holguin-Acuna et al., 2008). In addition to that, increase in porosity and decrease in density was observed when oat flour was blended with corn flour (Liu et al., 2000; Ozer et al., 2004). These findings are very similar to the present findings.

Yu (2011) mentioned that gelatinization of starch during extrusion processing has a big influence on bulk density of extruded products. Further, lower processing temperature or higher amount of starch proportion decreases the extent of gelatinization of the extruded products, which leads to low swelling and low volume of extruded products, therefore, bulk density of extruded products increases with the increasing of potato starch content.

According to Onwulata (2001), when milk proteins are added to starch ingredients for puffing, the density of the product tends to increase due to the protein affecting the expansion ratio. Moreover, Schoenfuss et al. (2013) mentioned that in a high quality extruded protein product, protein generally forms a textured matrix within which starch is evenly distributed as an inclusion, and also there are presence of steam generated voids too. Our findings are consistent with research by Limón-Valenzuela et al. (2010) who extruded milk protein concentrate (MPC) (0-10%) with a blend of cornstarch and maize, and observed an increase in bulk density as MPC concentration increased. Conversely, Onwulata et al. (2001) observed no significant effect on the bulk density as milk proteins including casein, whey protein concentrate and whey protein isolate were added to corn meal flour at 250 g/kg. Hence according to Schoenfuss et al. (2013) it's more likely that the product formula (type and amount of protein, starch, fiber, etc.), as well as the processing conditions, impacted the bulk density and differences observed when compared to other studies.

3.4 Conclusions

Extrusion processing variables, viz. finger millet flour (F), oat flour (O), potato starch (P) and whey protein isolate (W) were found their significant ($p<0.05$) effect on extrudate's drying process, the final product's moisture content, water activity and physical properties of the extrudate. Further, all of the above extrusion process variables showed their significant effect ($p<0.05$) on drying time at extrudate water activity (a_w) of 0.75. Interaction terms, viz. F-O, F-W, O-W and P-W were too found to have significant effect on extrudate moisture content at a_w of 0.75. Increase in the amount of whey protein isolate in the formulation significantly led to increase in extrudate's drying time ($p<0.05$). Also, increase in potato starch and finger millet flour proportions in the formulations significantly reduced the drying time to reach water activity of 0.75 and 18% (db) moisture content shortest drying time to achieve a water activity of 0.75 as well as final moisture content of 18% (db).

Further, extruded product's moisture content was found to decrease with increase in drying time, and the extrudates (made from the formulation mixtures of F-O-P) without protein

(0% W) dried faster than the higher protein content (10% W) products. In addition, oat flour's impact had found on water activity of the dried extrudates as the results showed the higher final water activity of the extrudate as the proportion of oat flour present in the formulation increases. The models for MR were found. Further F, O, P and W were affected linearly on MR [Value of p at Drying time: Up to 60 min. (**$0.01 \leq p < 0.05$**) and after 60 min. (**$p < 0.01$**)]. And the equations were expressed for each 15 minutes of time interval up to 105 minute and those can be used to predict the MR value of the product's at different drying times.

Extrusion processing variables as well as their interactive effects found to be significantly ($P < 0.05$) influenced on the physical properties (BS, BD, ER, RR and color) of the dried extruded products. Effect of whey protein isolate has been seen on RR and BD as higher W content in the formulation yielded high RR and BD of the dried extrudates. Likewise the same effect was noticed for finger millet flour on RR and BD as these both properties increased with increase in F content in the mixture whereas potato starch content showed the opposite effect. In addition, a* value of dried extrudates increased with higher proportion of oat flour content and lower proportion of potato starch content. More importantly higher potato starch content played a very important role to increase ER and BD as well as to decrease BS. The optimum formulation mixture proportion for BS, BD, ER, RR and color need to be looked at with respect to the intended type of product and desired physical property. This kind of study has its usefulness in identifying desirable operating conditions for targeted extruded products.

PREFACE TO CHAPTER 4

The study outlined in the previous Chapter 3 emphasized the importance of protein enriched finger millet based blends during extrusion and also on the identification of the processing variables that lead to desired quality extrudate. Extrudates just came out of the die were wet and showed a high water activity which indicated lack of stability. Hence, in order to get a dry products, the product was dried in an air convection drier to a final moisture content of 18% (dry basis) at 55°C with a controlled air flow rate of 0.1 m/s. The drying kinetics were studied. The study showed the significant effect of different variables on the drying behavior. The quality parameters of dried extrudates were tested viz. the appearance factor (Color [L*, a* and b* value]), texture attributes (breaking stress and expansion ratio) as well as bulk density and rehydration ratio to compare the difference among each runs. The dried product, although stable for storage, did not possess desirable sensory properties for direct consumption.

Chapter 4 is a study on comparing of frying versus microwave roasting of dried extrudates to improve their sensory quality and following these treatments, their physical characteristics viz. color (L*, a* and b* value), hardness, expansion ratio and rehydration ratio as well as sensory evaluation using Quality rating Test (QRT) were evaluated.

A part of this research was included in the poster presentation in International Congress on Engineering and Food (ICEF 12), Quebec City, Canada (2015). The experimental work and data analysis were conducted by candidate under the supervision of Dr. H. S. Ramaswamy. A more detailed manuscript is prepared for publication.

Salunke, S. and Ramaswamy, H. S. 2015. Effect of frying and microwave roasting on the extrusion dried products prepared from protein enriched formulations (draft).

CHAPTER 4

EFFECTS OF POST DRYING PROCESSES ON DRIED EXTRUDATE'S CHARACTERISTICS

Abstract

In this study, physical and sensory properties were evaluated after frying and microwave (MW) roasting of dried protein-enrich extruded products. Previously obtained extruded products, that were dried to 18% (db) moisture content, were subjected to deep frying in canola oil at 200 °C temperature for 330 s or microwave roasting in a 1000 W domestic MW oven for 100 s at 50% power. The moisture content of the product reduced to below 5% (db) after frying as well as microwave roasting. ANOVA and model generated response surface plots served to evaluate the significance of process variables on independent and interaction effects of extrusion process variables on the product properties such as expansion ratio, breaking stress, bulk density, rehydration ratio and color (L*, a* and b*). The result showed that increase in oat and finger millet flour content increased hardness for both fried and microwave roasted products, whereas an increase in potato starch content decreased the hardness. Further, a* value of fried samples had a strong positive correlation with overall acceptability of the samples. This confirms that oil content plays a significant role in modification of color & texture of fried samples in favor of their acceptability by consumers like other fried products available in market. MW roasting was the preferred snack with better correlation of sensory properties with analytical parameters of color and texture as compared to the fried extruded products. The results demonstrated that products with higher protein content and good sensory characteristics could be prepared using extrusion drying and MW roasting treatments transforming a junk food to a nutritious snack.

4.1 Introduction

Success of extrusion process, in order to develop the required characteristics in an extrudate, mainly depends on the multivariate inputs and that must be set at the correct levels to give the dependent physical conditions and chemical process changes within the barrel of the machine (Gill, 2013). And once the relationships between the independent variables and the dependent variables within the processor were established for an individual product type, they must be maintained close to their optimum levels, in a small processing window, to ensure that the extrudate variables were also kept at the required levels (Guy, 2001). The products obtained right after the extrusion may or may not contain the desired sensory characteristics. Hence the post extrusion processing such as frying or drying or microwave roasting makes modification of the physical, chemical and sensorial properties of the extruded products. So these processes play a crucial role to make the palatable snack product and also helping in terms of development of a desired color and flavor.

Ingredients viz. finger millet flour and oat flour have displayed many health benefits like cholesterol lowering effect, anti-carcinogenic effects and lowering the risk of cardio-vascular disease (CVD) as well as type 2 diabetes (Shashi et al., 2007; El Shebini et al., 2014). Apart from that, incorporation of whey protein into starch-based food is nutritionally beneficial. Further incorporation of oil with starch and protein during frying makes the products rich in major nutrient components (Gill, 2013). Hence this product fulfills the role as a balanced food in terms for tackling the malnutrition issues in most of the developing countries. In addition, the role of protein is not only limited as an essential component in the structure of many fried foods, but also as a constituent that participating in Maillard browning reaction with reduced sugar to form flavor and browning pigments. Hence the addition of whey protein isolate in finger millet flour blends is not only proposed for nutritionally benefits but also due to its significant role on flavor development as well.

Flavor development is a result of various chemical reactions and modification of food constituents at elevated temperature during frying. Reactions or modifications may involve breakdown of hydrogen bonding, formation of covalent bonding between amino acids, reaction of amino acids with sugar components and so on. Furthermore the color of fried foods can be seen as one of the range of input signals perceived by consumers, rather than just physical characteristics of the food. In addition to protein, starch gelatinization is crucial in frying, because it holds water and provide volume expansion (Chen et al., 2001). On top of this, water plays crucial role for determining the fried foods texture. Generally in protein-starch based extrudate frying has wide range of influence on product quality and their complex interaction in determining the texture, color and oil uptake of fried products. The consumer's acceptability of the product is mainly evaluated using a sensory evaluation. Sensory test is widely used by food industry and recognized as a core resource in any quality control program. Sensory information as a part of a marketing decision has given it unprecedented attention. It identifies and quantitatively models the key drivers for a product‘s acceptance by consumers (Gill, 2013).

However the effect of post extrusion processes viz. frying versus microwave roasting on physical and sensorial properties of whey protein isolate enriched finger millet flour mixture has not been studied. Therefore, the focus of this study was to investigate the influence of frying and microwave roasting parameters on physical and sensory properties of dried extrudates prepared from finger millet flour based blends and to evaluate and optimize the processing conditions (for frying "temperature and time" and for microwave roasting "power and time") for an acceptable quality product.

4.2 Materials and Methods

4.2.1 Materials

Finger millet flour was purchased from AAHA FOODS (Toronto, Canada) (composition provided by the manufacturer in %db: protein: 7%, fat: 2.3%, carbohydrate: 24% and dietary fiber: 48%). Oat flour and potato starch were procured from the local store known as bulk barn located at Vaudreuil-Dorion (composition of oat flour provided by the manufacturer: protein in %db: 13%, carbohydrate: 23%, fat: 10% and fiber: 40%) and (composition of potato starch provided by manufacturer in %db: carbohydrate: 26%). Whey protein isolate (90% protein) was also bought from the bulk barn (Vaudreuil-Dorion, Montreal). Commercially available canola oil was used as a frying medium.

4.2.2 Preparation of dried extrudates

As mentioned in previous chapter, the study was conducted with 20 experimental conditions according to a D-optimal mixture design using Design Expert Software (Version 9.0.3 State-Ease, Inc., Minneapolis, MN) with four variables and their predetermined set of constrained value (previous Chapter-Table 3.1). The independent variables with their constrained values were: finger millet flour (50-70%), oat flour (10-30%), potato starch (20-40%) and W (0-10%). Experiments were performed in a random order including replicate points to minimize the effect of experimental errors. The flours were mixed in a Hobart mixer (Hobart Food Equipment Group Canada, North York, ON) operating at a medium speed. The required amount of water and salt were added in the blends followed by mixing for 20 min and then allowed it to sit for overnight.

Extrusion process was carried out in a co-rotating twin screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P. R. China), consisting of three independent zones of controlled temperature in the barrel. The diameter of the screw was 30 mm. The length to diameter ratio of the extruder barrel was 20:1. The diameter of the hole in the die was 5 mm with a die length of 27 mm. The screw speed and the temperature of the third barrel section (metering section) were adjustable according to the desired levels. The process of feeding had done manually through a conical hopper, keeping the flights of the screw fully filled and avoiding accumulation of the material in the hopper.

Once a stable flow through condition was attained for the feed, extruded products were collected and cool dried under mild air flow conditions at room temperature overnight and then further dried in air convection drier at 55 °C with an air flow of 0.1 m/s to get a final moisture content of 18% (dry basis). Dried samples were stored in air tight plastic containers at room temperature and used for further analysis purpose.

4.2.3 Post drying treatments for sensory quality enhancement

(a) Frying

The effect of post extrusion frying process of whey protein isolate incorporated in finger millet flour blends has not been studied on typically extrusion-dried products. In order to fry, short cylindrical pieces of extruded snacks were cut from the extrudate (5 cm lengths) and subjected to frying under different conditions (Table 4.1). A digital frying pot (T-Fal FR4017 Deep Fryer, NJ) was filled with 2 L canola oil as a frying medium. The fryer was equipped with a metal mesh basket for placing the samples to be fried. The canola oil was stabilized at the required temperature and samples were fried in small batches. Samples were withdrawn at regular time interval of 30 s starting from 180 s to 420 s and excess oil was drained and blotted using paper towel and samples were put in plastic bag till equilibration to determine the required parameters.

Table 4.1 Conditions tested for optimization of frying parameters

Trial No.	Frying temperature (ºC)	Frying time* (sec)
1	**160**	**180 - 420**
2	**180**	**180 - 420**
3	**200**	**180 – 420**
4	**220**	**180 - 420**

*** = Effect of frying was studied for every 30 s time interval from 180 s to 420 s**

(b) Microwave roasting

In order to study the effect of microwave roasting on dried extrudates, the main focus was to optimize the combination of power and time to get the desired microwave roasted extrudates. And hence in order to roast, short cylindrical pieces of extruded snacks were cut from the extrudate (5 cm lengths) and subjected to microwave roasting under different conditions (Table 4.2). A domestic 1000 W microwave oven was used for this purpose. And observation was made for samples drawn at regular time intervals of every 15 s starting from 30 s to 120 s.

Table 4.2 Conditions tested for optimization of microwave roasting parameters

Trial No.	Power (%)	Total processing time* (sec)
1	**100**	**30 - 120**
2	**70**	**30 – 120**
3	**50**	**30 – 120**
4	**40**	**30 – 120**
5	**30**	**30 - 120**

*** = Effect of microwave roasting was studied for every 15 s time interval from 30 s to 120 s**

4.2.4 Measurement of physical characteristics

4.2.4.1 Color

Same as in section **3.2.10**

4.2.4.2 Expansion ratio

Same as in section **3.2.12**

4.2.4.3 Rehydration ratio

Same as in section **3.2.14**

4.2.4.4 Hardness

Hardness is very important textural characteristic from a processing viewpoint. In many cases, a high hardness value is not desirable for expanded products. Mechanical properties of the extrudates were determined by a three-point breaking test (Zasypkin and Lee, 1998) using a TA – XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 20 kg load cell. Extrudates cut to 35 mm long cylindrical pieces were placed on two rounded stands 30 mm apart. A third rounded crosshead was used to exert force in the middle of the bridge. The cross head was set to move down at 40 mm/min until breaking occurred. A force-distance curve was recorded and analyzed by Texture Exponent to calculate the peak force. The highest value of force was taken as a measurement for hardness. Five measurements were made on each product and the average value was used.

For the hardness measurement of fried and microwave roasted extrudates, each sample was processed up to pre-optimized condition (Frying: 200 ^{o}C for 330 s & MW roasting: 50 % power for total processing time of 100 s) and then stored in air tight plastic container. Further, all the measurements were observed after keeping one day in air tight plastic container at room temperature.

4.2.5 Sensory evaluation test

In this work, 12 untrained panelists (six male and six female with age between 20 and 35 years) were selected to participate in the study. The response variables were obtained by means of Quality Rating Test (QRT) (Muñoz et al., 1992) on a 7-point numerical scale (1 = very bad, 2=bad, 3=below fair-above bad, 4=fair, 5=below good-above fair, 6=good, 7 = very good). The measured characteristics of QRT were: color, crispiness, oiliness and overall quality.

For sensory analysis, the frying temperature of 200 °C was selected and the samples were withdrawn together at 330 sec. While in case of microwave roasted extrudates, the samples were roasted in a microwave for 100 sec in two consecutive cycle of 50-50 seconds each with 50% power. All the samples were prepared in duplicate. Samples were randomly evaluated in 6 sessions (10 samples per session among them 5 were deep fried and 5 were microwave roasted). Each panelist was provided with ginger ale to cleanse the palate between tasting. Fried and microwave roasted extrudates were served to panelists after third day of preparation.

4.2.5.1 Sensory evaluation scorecard

The following sensory evaluation card was used for gathering sensory data of test samples**.**

SENSORY EVALUATION SCORE CARD

Name:	**Date:**
Product: Finger millet based extruded snack food	
Ingredients: Finger millet flour, Oat flour, Potato starch, Whey protein isolate, Water, Salt and canola oil.	
Instructions: ➢ Taste the samples provided. And record your mark(s) in appropriate box using given scale which describes your feeling. ➢ An empty row is provided, right after the each row of attributes, for the purpose of writing down any comments if you wish! ➢ Ginger ale is provided for the purpose of cleansing the palate between tasting. And it is highly recommended you to drink before starting the new one as that will help you to avoid the carryover effect of previous one. Further, you are allowed to drink as much as you like. And also you can try the samples again, if once you have already tasted.	

Color (Black, Dark brown or Red)	Crispiness (Less crispy or Crispy)	Oiliness (Less oily or High oily)	Overall Acceptability (Consumable or non-consumable)

Very Good	Good	Above fair-below good	Fair	Below fair-above bad	Bad	Very Bad
7	6	5	4	3	2	1

Score	Sample Code									
	456	DEF	951	PQR	789	ABC	357	XYZ	123	JKL
COLOR										
CRISPINESS										
OILINESS										
OVERALL ACCEPTABILITY										

4.2.6 Correlation coefficient (r)

One of the more frequently reported statistical methods involves correlation analysis where a correlation coefficient is reported representing the degree of linear association between two variables (Taylor, 1990). Pearson's correlation coefficient is a statistical measure of the strength of a linear relationship between paired data. The Pearson correlation coefficient r can be defined as follows. Suppose that there are two variables X and Y, each having n values X_1, X_2, . . . , X_n and Y_1, Y_2, . . . , Y_n respectively. Let the mean of X be $\bar{X}$ and the mean of Y be $\bar{Y}$.

Pearson's r is

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \qquad \text{………... (4.1)}$$

In a sample it is denoted by "r" and is by design constrained as follows:

$-1 \leq r \leq 1$

4.3 Results and Discussion

4.3.1 Fried extrudates

Deep-fat frying is considered as one of the oldest processes of food preparation and consists basically in the immersion of food pieces in hot oil. It has been widely used in the food industry because it offers immense advantages and the acceptance rate of food product undergoing frying is very high in terms of sensory quality. Frying is used as a method for creating unique flavors and textures in processed foods to improve their overall palatability (Yu, 2013).

The high temperature frying process causes the transfer of the oil to the food, and concurrent water evaporation. Bemiller and Whistler (1996) reported that typically it leads to the changes that improves textural characteristics of fried foods, and also causes a complex group of chemical reactions, like Maillard reaction and caramelization, leading to the development of color. Yu (2013) mentioned that deep fat frying is a simultaneous cooking and drying process through contact with hot oil and it involves simultaneous heat and mass transfer. Oil plays a dual role in terms of serving as a heat transfer medium and in improving the texture and flavor of the product.

Most frying processes are carried out at an oil temperature between 160 and 180°C and are characterized by high drying rates (Baumann and Escher, 1995). Critically, this fast drying leads to improvement of the mechanical and structural properties of the final product. Farkas et al. (1996) reported that these conditions lead to high heat transfer rates, rapid cooking, browning, texture and flavor development. Oil added during the frying process is one important constituent to improve textural quality of fried starch based products apart from their nutritional value. Generally, in protein-starch enriched extrudate, frying has wide range of influence on product quality and their complex interaction in determining the texture, color and oil uptake of fried products.

The main purpose of frying was to enhance the sensory attributes in terms of increasing acceptability of dried extrudates. Further frying process led to several changes in the physical properties of extrudates. Hence, the experimental arrangements (test run number) and data on the physical properties of fried extrudates for hardness (H), expansion ratio (ER), rehydration ratio (RR) and color (L*, a*, b* values) of extruded products are shown in Table 4.4. Also ANOVA was carried out for the analysis of above physical characteristics (Table 4.5). Moreover, these properties were discussed under two broad sub category which were texture and color respectively.

Table 4.3 Response values of the instrumental tests for fried extrudates

Run	L* value	a* value	b* value	Rehydration ratio (%)	Expansion ratio	Hardness (N)
1	14.78 (3.26)	8.14 (0.93)	-1.38 (1.27)	58.21 (5.78)	2.08 (0.17)	39.89 (9.06)
2	10.50 (1.07)	6.87 (0.98)	-0.83 (0.92)	51.09 (4.60)	1.92 (0.05)	46.96 (6.19)
3	9.63 (2.01)	7.38 (0.91)	0.97 (1.62)	56.59 (2.62)	2.08 (0.07)	39.53 (4.03)
4	12.90 (3.66)	7.02 (0.35)	0.56 (2.52)	76.37 (5.64)	1.99 (0.11)	26.37 (12.82)
5	11.48 (1.47)	7.87 (0.56)	0.44 (1.22)	73.10 (3.54)	1.86 (0.02)	25.07 (16.54)
6	8.94 (1.02)	8.93 (0.13)	-4.46 (1.87)	72.29 (4.02)	1.88 (0.05)	18.78 (8.59)
7	6.09 (1.86)	8.18 (0.21)	-3.35 (1.67)	52.62 (7.75)	2.08 (0.04)	32.09 (11.98)
8	7.35 (0.23)	9.31 (0.18)	-0.73 (2.42)	52.43 (3.22)	2.05 (0.02)	43.75 (3.37)
9	7.02 (5.62)	8.80 (0.84)	-4.80 (3.62)	58.76 (5.80)	1.73 (0.10)	32.27 (15.74)
10	10.06 (4.25)	8.76 (0.71)	-1.88 (1.02)	83.98 (2.96)	1.89 (0.05)	43.32 (8.08)
11	10.68 (2.47)	9.14 (0.12)	-3.01 (1.72)	87.96 (7.49)	1.98 (0.04)	43.03 (5.62)
12	13.57 (3.56)	8.27 (0.36)	2.78 (2.08)	65.90 (9.21)	1.88 (0.15)	39.48 (6.94)
13	13.12 (4.47)	7.32 (0.79)	-2.92 (4.75)	68.68 (3.25)	1.92 (0.09)	26.01 (3.31)
14	18.95 (3.71)	9.70 (0.42)	-7.34 (3.26)	58.06 (5.84)	1.85 (0.03)	38.90 (15.44)
15	9.57 (2.89)	8.81 (0.51)	-8.16 (2.10)	59.76 (6.64)	1.86 (0.02)	24.97 (7.75)
16	11.28 (1.05)	8.20 (0.22)	-4.18 (1.36)	78.89 (1.95)	1.82 (0.01)	36.34 (4.52)
17	9.39 (1.22)	9.20 (0.32)	-3.72 (2.54)	58.79 (2.56)	2.10 (0.05)	27.11 (16.48)
18	15.12 (3.87)	6.90 (0.11)	0.19 (3.21)	69.62 (8.38)	2.06 (0.07)	23.98 (10.37)
19	12.18 (2.95)	7.62 (0.43)	-3.66 (1.72)	70.72 (1.98)	1.82 (0.11)	27.59 (3.62)
20	10.02 (1.47)	8.71 (0.16)	-6.82 (1.97)	64.12 (5.24)	1.81 (0.04)	28.72 (6.75)

Table 4.4 ANOVA results for fitted models of physical characteristics of fried extrudates

Responses	Source	Sum of squares	Df	Mean squares	F-value	P-value
	Regression	157.17	9	17.46	8.92	0.0010*
	Lack of fit	12.67	5	2.53	1.83	0.2610
L*	Pure error	6.91	5	1.38		
	Residual	19.58	10	1.96		
	Total	176.75	19			
	Regression	12.43	9	1.38	9.41	0.0008*
	Lack of fit	0.79	5	0.16	1.17	0.4345
a*	Pure error	0.68	5	0.14		
	Residual	1.47	10	0.15		
	Total	13.89	19			
	Regression	106.61	3	35.54	10.17	0.0005*
	Lack of fit	50.06	11	4.55	3.88	0.0729
b*	Pure error	5.86	5	1.17		
	Residual	55.92	16	3.49		
	Total	162.53	19			
	Regression	0.11	3	0.037	4.74	0.0149*
	Lack of fit	0.11	11	9.089E-003	1.85	0.2567
Expansion ratio	Pure error	0.025	5	4.900E-003		
	Residual	0.12	16	7.780E-003		
	Total	0.24	19			
	Regression	1889.32	9	209.92	7.87	0.0017*
	Lack of fit	142.99	5	28.60	1.15	0.4393
Rehydration ratio	Pure error	123.87	5	24.77		
	Residual	266.85	10	26.69		
	Total	2156.18	19			
	Regression	657.76	3	219.25	5.62	0.0079*
	Lack of fit	436.71	11	39.70	1.06	0.5104
Hardness	Pure error	187.68	5	37.54		
	Residual	624.39	16	39.02		
	Total	1282.14	19			

*** significant at P < 0.05, df: degrees of freedom.**

Table 4.5 Analysis of Variance (ANOVA) for the fit of experiment data to D-optimal mixture design (Fried extrudates)

Source	L*	a*	b*	ER	RR	H
R^2	0.8892	0.8944	0.6560	0.4708	0.8762	0.5130
Adj R-Squared	0.7895	0.7994	0.5914	0.3716	0.7649	0.4217
Pred R-Squared	0.6049	0.4991	0.4918	0.2330	0.5781	0.2847
Adeq Precision	13.08	9.23	9.62	6.98	9.12	6.45

Table 4.6 Regression equations for physical properties of fried extrudates (taking significant parameters on the basis of probability level $p \leq 0.05$)

Physical properties	Equations (Actual value)	Mean Standard Error
L*	$\mathbf{Y_{L^*}} = (0.11994 * F) – (0.0449781 * O) + (0.688573 * P) + (18.3548 * W) + (0.0076756 * F * O) - (0.0074386 * F * P) – (0.211672 * F * W) – (0.0206354 * O * P) – (0.113769 * O * W) – (0.23269 * P * W)$	0.84
a*	$\mathbf{Y_{a^*}} = (- 0.00252462 * F) + (0.604974 * O) – (0.228316 * P) – (3.06698 * W) – (0.00467232 * F * O) + (0.00810177 * F * P) + (0.0358168 * F * W) – (0.00921797 * O * P) + (0.0369923 * O * W) + (0.0384194 * P * W)$	0.23
b*	$\mathbf{Y_{b^*}} = (- 0.0786098 * F) – (0.031157 * O) + (0.140273 * P) – (0.445487 * W)$	0.45
ER	$\mathbf{Y_{ER}} = (0.0139194 * F) + (0.0243427 * O) + (0.0276802 * P) + (0.0197992 * W)$	0.02
RR	$\mathbf{Y_{RR}} = (0.71619 * F) + (7.81218 * O) + (3.90597 * P) + (31.5408 * W) – (0.0489175 * F * O) – (0.0348315 * F * P) – (0.367133 * F * W) – (0.25807 * O * P) – (0.482332 * O * W) – (0.302538 * P * W)$	3.11
H	$\mathbf{Y_{H}} = (0.189479 * F) + (1.06896 * O) + (0.210492 * P) + (0.146991 * W)$	1.52

Table 4.7 Analysis of Variance (ANOVA) for the individual variables and for the interactions between them (fried extrudates considering significant parameters on the basis of probability level $p \leq 0.05$)

Source	L*	a*	b*	RR	ER	Hardness
Model	0.0010	0.0008	0.0005	0.0017	0.0149	0.0079
Linear Mixture	0.6632	0.0002	0.0005	0.0305	0.0149	0.0079
AB	0.5542	0.2033	-	0.3155	-	-
AC	0.5588	0.0369	-	0.4607	-	-
AD	0.0002	0.0053	-	0.0226	-	-
BC	0.1122	0.0175	-	0.0002	-	-
BD	0.0152	0.0060	-	0.0073	-	-
CD	0.0002	0.0058	-	0.0689	-	-

***0.01<P<0.05; **P≤0.01; ns=not significant**

4.3.1.1 Texture

The textural properties of the fried extrudate was studied by means of physical properties viz. expansion ratio, hardness and rehydration ratio. The expansion ratio gives an indication of the puffing ability of the product after frying. It is related with the product's crispiness, water absorption, water solubility, and crunchiness. While the hardness was observed by measuring the maximum force required to break the extrudate. Rehydration ratio is a measurement of the ability of the product to gain moisture. It has application in a product such as breakfast cereal and similar category of products which usually rehydrated before consumption.

(a) <u>Expansion Ratio</u>:

The expansion ratio, hardness and rehydration ratio of fried extrudates were significantly ($p<0.01$) affected by proportion of finger millet flour, oat flour, potato starch and WPI in the blends. The value of expansion ratio for fried extrudates had ranged from 1.73 to 2.10 (Table 4.3). The contour graph is provided to display the effect of individual ingredients on the expansion ratio in Figure 4.1(a).

The ratio of expansion was found to decrease with the increase in the proportion of finger millet flour content and decrease in potato starch content proportion in the dried extrudates. Thus to achieve a high expansion ratio during frying, dried extrudates should contain higher potato starch proportion, meanwhile, lower proportion of oat flour. Further, whey protein isolate also has its negative impact as the expansion ratio decrease with increase in WPI proportion. The same findings was presented by Kannadhason et al. (2007) as they had reported that protein is found to have a negative impact on the expansion of the extruded products and therefore as the protein content in the respective blends increased, a marginal decrease in expansion ratio could be observed.

Starch plays a crucial role in determining the texture of many foods and texture is one of greater concern to both consumers and food manufacturers (Whistler and Paschall 1965). Several researchers demonstrated that expansion ratio of the cereals by direct heating or extrusion depended on the degree of starch gelatinization (Chinnaswamy and Bhattacharya 1983, 1986; Bhattacharya and Hanna 1987; Chinnaswamy and Hanna 1988). Consequently, starch conversion during extrusion is also influenced by other components, especially proteins and fats (Lin et al. 1997). Moreover, starch expansion mainly depends on its degree of gelatinization, and during the process of extrusion cooking up to 90% of the starch can be gelatinized, which promotes the molecular intertwining of the ingredients in the feed mixture (Chinnaswamy and Hanna 1988). Kannadhason et al. (2007) noticed reduction of expansion ratio with increase in all the three starches content (cassava, potato and corn).

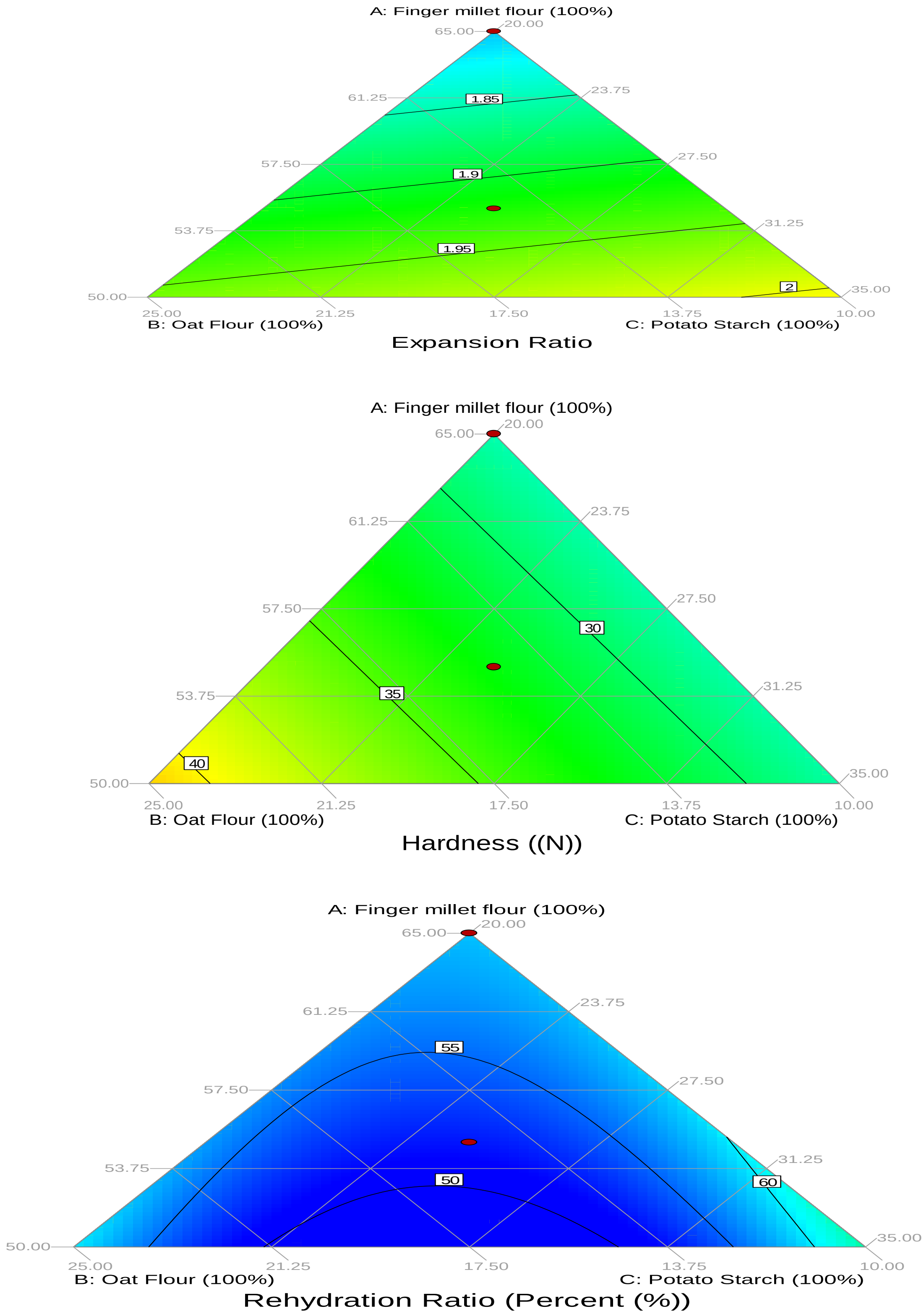

Figure 4.1 Contour graph for fried extrudate's a) expansion ratio, b) hardness and c) rehydration ratio as a function of formulation mixture variable at 5% W proportion

(b) Hardness:

The following Figure 4.1(b) shows the contour graph of the individual ingredient's effect on hardness of fried extrudates. And in case of hardness, the highest hardness was measured as 46.96 N and the lowest came out to be 18.78 N (Table 4.3). The effects of the proportion of ingredients on hardness were clearly seen as the increase in oat flour content increased hardness, whereas increase in potato starch and WPI contents decreased hardness. Furthermore, samples with higher values of hardness may be considered sensorial undesirable. In many cases, hardness higher than 200 N is not a desirable attribute for expanded snacks (Forsido & Ramaswamy, 2011). The prepared new products in this study have far less hardness (maximum hardness was 46.96 N in case of fried extrudates).

(c) Rehydration ratio:

While the measured values for a rehydration ratio were in the range of the 51.1-88.0 (Table 4.3). The response surface curve for RR values of fried extrudates was found to be concaved at mid potato starch content showing there was an initial decrease followed by an increase in RR as a function of potato starch level. This can be seen in Figure 4.1(c) that shows the contour graph for effect of individual process variables on RR of fried extrudates. Further RR has close relationship with ER, where higher ER indicates higher porosity of the extrudate and resulted in higher water absorbing capacity (Yu et al., 2012). Hence, extrudates fried at temperature of 200°C for 330 sec reported the high ER value, which then contributes to the increase in RR. Moreover, Correlation analysis showed that RR was negatively related to fried extrudate's ER ($r=-0.26$).

4.3.1.2 Color

Color is an important characteristic of extruded foods. Color changes can give information about the extent of browning reactions such as caramelization, Maillard reaction, degree of cooking and pigment degradation that take place during the extrusion process (Altan et al., 2008). Color is one of the physical properties that is often used by food customers and manufacturers to qualitatively assess the quality of feed and food materials (Turner, 1995; Yu and Ramaswamy 2012). Processing conditions during extrusion often lead to color change by non-enzymatic browning which results from Maillard reactions or by caramelization between proteins and reducing sugars (Berset, 1989).

The color of extruded products was measured in terms of L* (lightness), a* (redness), and b* (yellowness) values. Analysis of variance (ANOVA) was used to test the significance of the product formulation on the color parameters. Further, the regression equation for the relationship between L* value (YL*), a* value (Ya*), b* value (Yb*) and independent variables in terms of coded variables is presented in Table 4.3. The main goal of study was to achieve the lighter color fried extrudates viz. golden yellow or red or slight brown.

(a) L* value:

With higher proportion of finger millet included in the mixture, lower L* value of fried extrudate was observed and formulations with higher proportion of potato starch showed a higher L* value of fried extrudates. In addition, finger millet flour used in our study was relatively dark in comparison with the other ingredients used (i.e., potato starch and WPI). Therefore, increase in the finger millet flour proportion in the formulation resulted in the decrease in brightness of fried extrudate (L* value trend in Figure 4.2). For any given formulation, the trend observed was an initial decreased followed by an increased in L* value as the increase in WPI content (Fig. 4.2). The similar finding was observed for study of protein rich extrudates by Forsido & Ramaswamy (2011).

(b) a* value:

The value of a* was found to be increased with decrease in potato starch content (Figure 4.2). In addition, the effect showed by WPI on a* value of extrudates was positive as value of a* showed increased with increase in WPI content. While the value of b* showed increased with increase in finger millet flour and oat flour content as well as decrease in potato starch content.

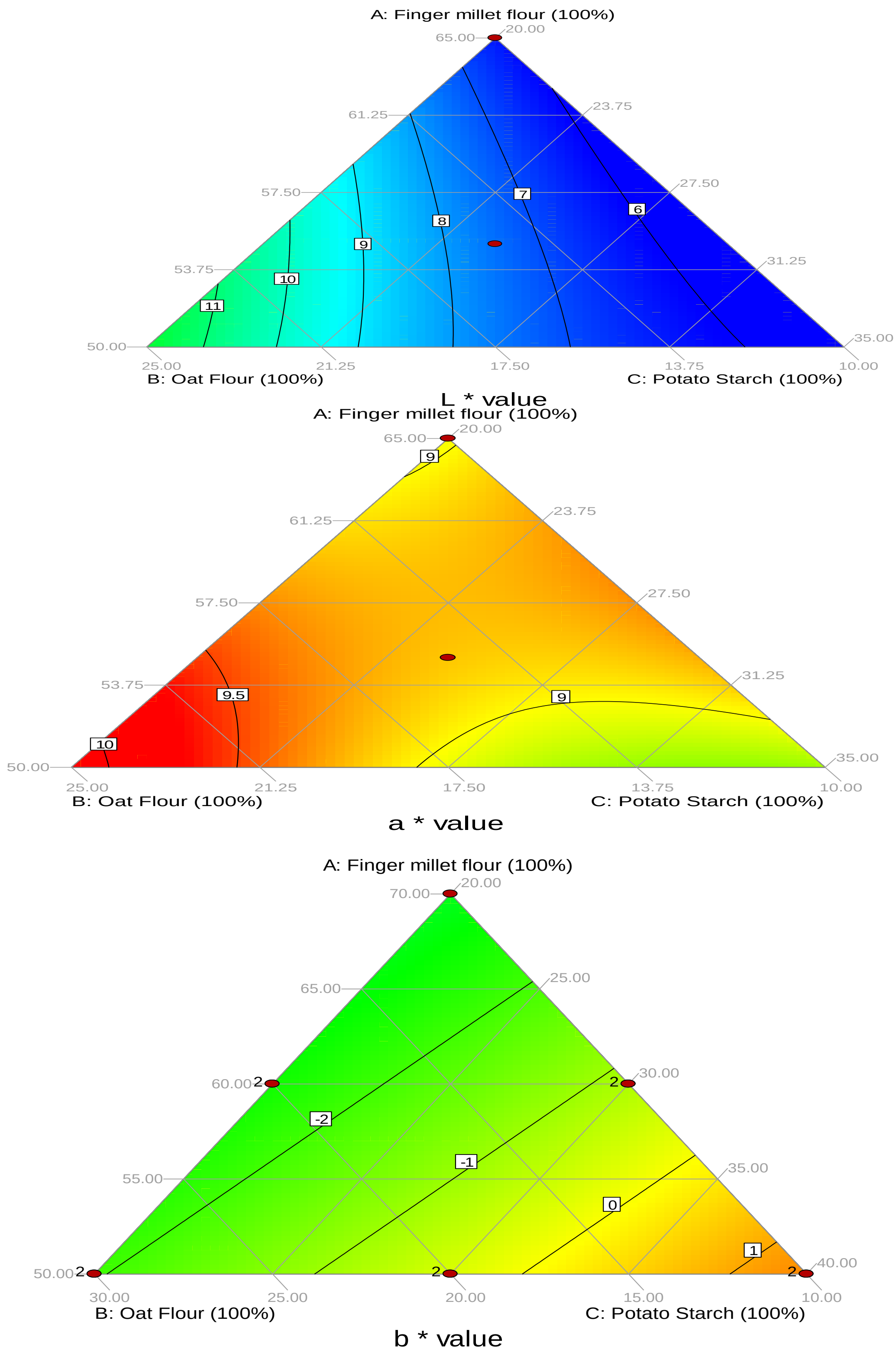

Figure 4.2 Contour graph for fried extrudate's L*, a* and b* value as a function of formulation mixture variable at 5% W proportion

The following Figure 4.3 (a) and (b) shows the actual products for all the trials after frying and microwave roasting respectively.

(a)

(b)

Figure 4.3 Extruded products after (a) frying and (b) microwave roasting

4.3.2 Microwave roasted extrudates

Two of the challenges with microwave food products are that it is often difficult to achieve the desired flavor that matches products prepared in a conventional oven or by frying.

Specifically achieving the browning up to the mark of consumer's expectation is not possible in microwave cooking. And hence the resulted product is lacking in flavor and color. The typical browning which occurs when foods are heated by conventional means produces not only the desired brown pigments but also produces a variety of desirable flavors. Importantly, flavors and colors generated as a result of the Maillard reaction plays a critical role behind the commercial success of processed foods. And hence recent interest in the microwave generation of Maillard flavors and colors have been challenging for a food industry while it has highly demanded by the consumer (Ibrahim et al., 2012).

Within the electromagnetic spectrum, microwave radiation is characterized by being situated in the frequency interval between 300 MHz and 300 GHz, with those normally used for the industrial processing of foods being between 915 and 2450 MHz and, for domestic use, of 2450 MHz (Pei, 1982). Microwave ovens can be built for industrial (continuous or batch processes), laboratory or domestic use. Industrial equipment present greater process control, but are costly and designed for large scale, which limits their use in research. Those developed for laboratory use are also costly, due to the need of heating, pressure and time control mechanisms to increase the reproducibility of the results. Therefore, many researchers stopped adapting domestic microwave ovens, which results in lower cost equipment. Domestic microwave ovens do not have a uniform distribution of microwave radiation, as they were not designed for such. They produce interference between the microwaves and, thus, some parts of the oven receive a greater incidence than others.

Senise & Jermolovicius (2004) reported that the technically possible applications of microwaves, at the industrial level in the food industry are the drying of pasta products, dehydration, blanching, sterilization, pasteurization, cooking and thawing. However, nowadays these applications have increased with the use of microwaves for chemical reactions, insect and germination control, production of expanded cereals or tubers, etc. The advantages of microwave cooking are a shorter processing time, higher yield and better quality of the final product in terms of both sensory and nutritional aspects when compared with conventional processing techniques (Sacharow & Schiffmann, 1992; Hoffman & Zabik, 1985).

In microwave heating of foods, water plays a very important role. When microwave energy is applied to a food, water dipoles try to follow the rapidly changing field, which results in a temperature increase (Ryynanen 1995). Dielectric properties of water depend highly on its structure and molecular organization. During microwave expansion of cereal pellets, the microwave energy heats the product through the vibrational energy imparted on moisture. Upon heating, moisture generates the superheated steam necessary for expansion, which accumulates at nuclei in the glassy matrix, creating a locally high pressure. As the cereal matrix undergoes a phase transition from the state of glassy to the rubbery, it starts to yield under the high superheated steam pressure and expansion takes place (Boischot et al., 2003).

The main aspects that should be considered are: dielectric properties of foods, quantity of energy coupled by a food product and distribution within the product, microwave time and frequency necessary to heat the food product, temperature, pressure and electric field parameters (Mudgett, 1982; Rocha, 2002). Microwave energy can penetrate a food material and produce heat internally by molecular friction of the electrical dipoles and charged molecules under an oscillating field of specific frequency, and also by the heat transferred by conduction, convection, and evaporation (Mudgett 1982). A major problem encountered with microwave heating is the uneven temperature profile developed inside the heated product (Goedeken 1994; Remmen et al 1996). As foods are poor heat conductors, any non-uniformity generated by the electric field in the microwave oven results in large temperature variations in the product (Goedeken 1994).

Majority of the snacks available in the market are fried which means it is consider as unhealthier and placed into junk food category due to rich in fat. Hence microwave roasting of the dried extrudates has been studied with the objective to give a healthier snack food option. Further microwave roasting led to several changes in the physical properties of extrudates. Hence, basic idea was to study the changes in physical properties of microwave roasted extrudates with that of fried extrudates. The experimental arrangements (test run number) and data on the physical properties of microwave roasted extrudates for hardness (H), expansion ratio (ER), rehydration ratio (RR) and color (L*, a*, b* values) of extruded products are shown in Table 4.8. Also ANOVA was carried out for the analysis of above physical characteristics and result presented in Table 4.9 and 4.10 respectively. Further, Table 4.11 summarized the regression equations of the individual physical properties of microwave roasted extrudates in terms of actual factors.

Table 4.8 Response values of the instrumental tests for microwave-roasted extrudates

Run	L* value	a* value	b* value	Rehydration ratio (%)	Expansion ratio	Hardness (N)
1	21.58 (2.65)	6.81 (0.50)	10.99 (2.08)	120.76 (5.12)	2.17 (0.08)	25.50 (4.41)
2	20.95 (5.17)	3.99 (1.09)	8.17 (1.51)	142.80 (2.59)	2.41 (0.05)	35.48 (7.52)
3	23.08 (1.53)	5.05 (0.42)	10.21 (2.02)	192.12 (5.51)	2.19 (0.02)	35.55 (11.68)
4	22.16 (2.08)	4.49 (0.18)	9.49 (3.72)	324.81 (3.98)	2.26 (0.10)	22.69 (8.65)
5	24.04 (3.27)	4.36 (1.00)	9.91 (3.01)	268.00 (7.17)	2.18 (0.02)	33.65 (5.21)
6	19.83 (4.68)	4.99 (0.60)	10.69 (2.89)	241.83 (4.01)	2.14 (0.06)	14.78 (16.35)
7	21.28 (2.95)	4.99 (0.91)	10.61 (1.85)	227.75 (9.98)	2.26 (0.04)	35.84 (3.36)
8	27.31 (4.47)	5.05 (0.27)	10.30 (2.58)	218.62 (2.74)	1.99 (0.04)	31.43 (8.97)
9	24.78 (1.89)	6.13 (0.62)	12.11 (1.25)	168.16 (5.28)	1.87 (0.06)	36.69 (4.52)
10	28.42 (1.81)	5.37 (1.03)	10.55 (2.60)	215.64 (4.45)	1.96 (0.03)	33.91 (2.65)
11	30.18 (3.58)	6.56 (0.26)	12.07 (1.72)	178.09 (8.03)	2.00 (0.01)	39.11 (8.17)
12	26.58 (2.25)	5.23 (0.80)	11.49 (1.25)	218.48 (3.49)	2.10 (0.05)	30.12 (5.47)
13	29.83 (5.02)	5.81 (0.52)	11.65 (2.39)	423.00 (10.68)	2.06 (0.09)	15.44 (2.88)
14	27.68 (2.68)	6.50 (0.90)	12.25 (3.06)	113.72 (4.04)	1.94 (0.04)	22.55 (2.52)
15	25.65 (3.02)	7.58 (0.47)	14.04 (2.04)	292.13 (7.25)	1.90 (0.07)	18.75 (12.05)
16	29.26 (4.12)	5.68 (1.02)	11.39 (1.31)	370.68 (9.11)	2.01 (0.12)	19.25 (3.17)
17	25.81 (3.52)	7.30 (0.61)	12.58 (3.11)	286.67 (4.01)	2.23 (0.04)	26.71 (6.34)
18	20.34 (6.85)	3.16 (0.25)	7.82 (1.97)	297.85 (2.36)	2.27 (0.06)	26.99 (3.12)
19	27.69 (1.02)	5.68 (0.12)	11.69 (2.02)	95.15 (7.77)	1.87 (0.05)	36.52 (15.79)
20	25.29 (5.62)	7.72 (0.82)	15.21 (2.59)	234.19 (4.58)	1.86 (0.02)	19.64 (9.60)

Table 4.9 ANOVA for physical characteristics of microwave roasted extrudates.

Responses	Source	Sum of squares	Df	Mean squares	F-value	P-value
	Regression	155.91	3	51.97	16.48	<0.0001*
	Lack of fit	41.60	11	3.78	2.13	0.2079
L*	Pure error	8.86	5	1.77		
	Residual	50.46	16	3.15		
	Total	206.37	19			
	Regression	19.48	3	6.49	12.66	0.0002*
	Lack of fit	5.67	11	0.52	1.01	0.5319
a*	Pure error	2.54	5	0.51		
	Residual	8.21	16	0.51		
	Total	27.68	19			
	Regression	39.67	3	13.22	11.98	0.0002*
	Lack of fit	11.75	11	1.07	0.90	0.5898
b*	Pure error	5.91	5	1.18		
	Residual	17.66	16	1.10		
	Total	57.33	19			
	Regression	0.34	3	0.11	11.81	0.0002*
	Lack of fit	0.12	11	0.011	1.89	0.2497
Expansion ratio	Pure error	0.030	5	5.900E-003		
	Residual	0.15	16	9.511E-003		
	Total	0.49	19			
	Regression	1.290E+005	9	14335.32	14.46	0.0001*
	Lack of fit	5031.86	5	1006.37	1.03	0.4869
Rehydration ratio	Pure error	4879.46	5	975.89		
	Residual	9911.32	10	991.13		
	Total	1.389E+005	19			
	Regression	1070.40	9	118.93	13.21	0.0002*
	Lack of fit	53.76	5	10.75	1.48	0.3380
Hardness	Pure error	36.26	5	7.25		
	Residual	90.02	10	9.00		
	Total	1160.42	19			

*** significant at $P < 0.05$, df: degrees of freedom.**

Table 4.10 Analysis of Variance (ANOVA) for the fit of experiment data to D-optimal mixture design (Microwave roasted extrudates)

Source	L*	a*	b*	ER	RR	H
R^2	**0.7555**	**0.7035**	**0.6920**	**0.6888**	**0.9287**	**0.9224**
Adj R-Squared	**0.7096**	**0.6480**	**0.6342**	**0.6305**	**0.8645**	**0.8526**
Pred R-Squared	**0.6219**	**0.5380**	**0.4997**	**0.5417**	**0.6894**	**0.6926**
Adeq Precision	**11.21**	**11.04**	**10.92**	**10.39**	**14.25**	**9.63**

Table 4.11 Regression equations for physical properties of microwave roasted extrudates (taking significant parameters on the basis of probability level p ≤ 0.05)

Physical properties	Equations (Actual value)	Mean Standard Error
L*	$\mathbf{Y_{L*}}$ = (0.368104 * F) + (0.3881 * O) – (0.05687 * P) + (0.0637915 * W)	0.43
a*	$\mathbf{Y_{a*}}$ = (0.0829719 * F) + (0.068793 * O) – (0.0278154 * P) + (0.215003 * W)	0.17
b*	$\mathbf{Y_{b*}}$ = (0.172477 * F) + (0.0838048 * O) – (0.0231509 * P) + (0.294382 * W)	0.26
ER	$\mathbf{Y_{ER}}$ = (0.0137183 * F) + (0.0216267 * O) + (0.0363161 * P) + (0.0135872 * W)	0.02
RR	$\mathbf{Y_{RR}}$ = (-22.1089 * F) – (92.0617 * O) + (7.93326 * P) + (0.78972 * W) + (2.60093 * F * O) + (0.534616 * F * P) + (0.809411 * F * W) – (0.884119 * O * P) – (1.18386 * O * W) – (0.328285 * P * W)	18.97
H	$\mathbf{Y_{H}}$ = (1.51976 * F) + (8.52481 * O) – (1.84327 * P) – (26.5292 * W) – (0.198933 * F * O) + (0.00797338 * F * P) + (0.261163 * F * W) + (0.0529521 * O * P) + (0.300889 * O * W) + (0.29102 * P * W)	1.81

Note: Standard mean errors were estimated using D-expert software.

Table 4.12 Analysis of Variance (ANOVA) for the individual variables and for the interactions between them (microwave roasted extrudates considering significant parameters on the basis of probability level $p \leq 0.05$)

Source	L*	a*	b*	RR	ER	Hardness
Model	< 0.0001	0.0002	0.0002	0.0001	0.0002	0.0002
Linear Mixture	< 0.0001	0.0002	0.0002	0.0386	0.0002	0.0012
AB	-	-	-	< 0.0001	-	< 0.0001
AC	-	-	-	0.0822	-	0.7686
AD	-	-	-	0.3532	-	0.0081
BC	-	-	-	0.0078	-	0.0637
BD	-	-	-	0.2062	-	0.0048
CD	-	-	-	0.7243	-	0.0071

***0.01<P<0.05; **P≤0.01; ns=not significant**

4.3.2.1 Texture

As discussed previously, texture of the extrudate was measured by analysing the expansion ratio, hardness and rehydration ratio. We can see the changes of these physical properties when dried extrudates undergo microwave roasting.

(a) <u>Expansion ratio</u>:

In case of microwave roasted extrudates, the expansion ratio was found to be 1.86 to 2.41. Hence the expansion of extrudate was higher in case of microwave roasted extrudate with compared to dried and fried extrudate. Hence we can use the microwave roasting to achieve the desired puffiness of the extrudates. The ratio of expansion was found to increase with the increase in the proportion of potato starch content and decrease in oat flour content proportion. Thus to achieve a high expansion ratio during MW roasting, dried extrudates should contain higher potato starch proportion, meanwhile, lower proportion of oat flour (Fig. 4.4).

(b) <u>Hardness</u>:

The highest hardness was calculated as 39.11 N and the lowest came out to be 14.78 N. The hardness value of microwave roasted extrudates were significantly ($p<0.01$) affected by interaction effects of finger millet flour-oat flour, finger millet flour-WPI, oat flour-WPI and potato starch-WPI. Quadratic regression coefficient analysis for microwave roasted extrudates disclosed that hardness was positively related to each process variable (except potato starch and WPI as well as finger millet flour-oat flour interaction; negative quadratic regression coefficient) as well as the interactive effect of F-P, F-W, O-P, O-W and P-W. Fig 4.4 shows that increased in hardness was directly related to finger millet flour and oat flour content while it's inversely related to potato starch content.

(c) <u>Rehydration ratio</u>:

The rehydration ratio values were ranged from the 95.15-423.00. The value of RR was too high (viz. more than 200) in some of the extrudate undergone microwave roasting. Further higher RR means the product has higher potential to absorb the water. So the product may have very high tendency to become soggy compared with dried and fried microwave roasted extrudates. This can be very well explained by the fact presented earlier that higher ER of the products lead to increase in porosity. And hence finally the product has higher potential to absorb the water. The increased in rehydration ratio is directly proportional to potato starch content and inversely proportional to finger millet and oat flour content (Fig. 4.4).

Further the contour graph showing the effect of individual process variable on expansion ratio, rehydration ratio and hardness are provided (Fig. 4.4).

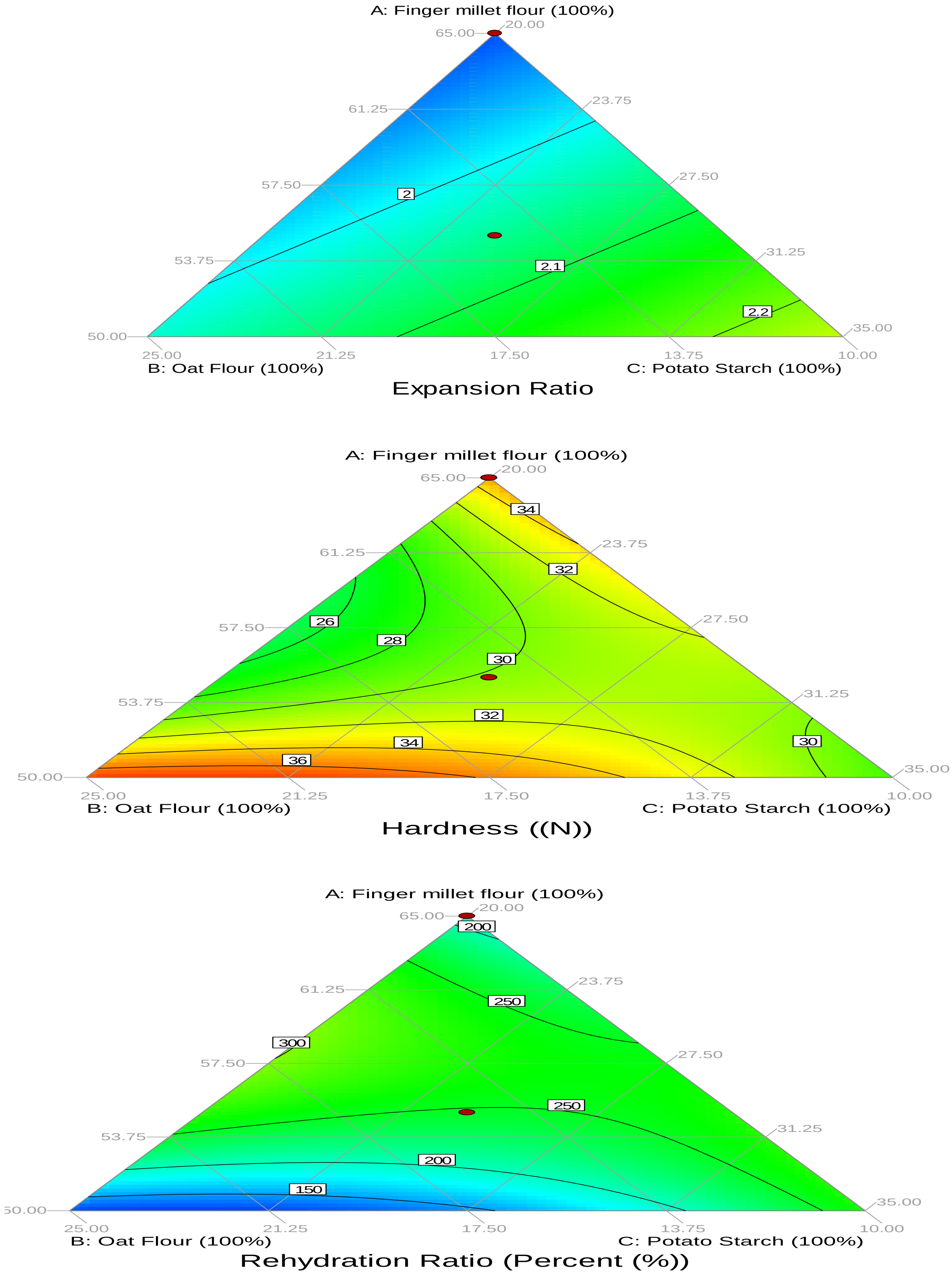

Figure 4.4 Contour graph for microwave roasted extrudate's Expansion ratio, Hardness and Rehydration ratio as a function of formulation mixture variable at 5% W proportion

4.3.2.2 Color

Color is one of the most vital attributes of any food product due to consumer acceptability considerations. The color of extruded products was measured in terms of L* (lightness), a* (redness), and b* (yellowness) values. The values of L*, a*, and b* under different designed experimental conditions are given in Table 4.8. The results indicated that the L* values of extruded products varied between 19.8 and 30.2, a* values ranged from 3.16 to 7.72 and b* values varied from 7.82 to 15.2.

(a) <u>L* value</u>:

Figure 4.5 is the contour graph indicating the effect of process variable on L* value, a* value and b* value of microwave roasted extrudates. The value of L* was decreased with increase in potato starch content (Fig. 4.5). This is result of higher degree of starch gelatinization during microwave roasting. The interaction between F-O was positive whereas the interaction between F-P, F-W, O-P, O-W and P-W showed negative coefficient. The negative coefficient interactions resulted in the concave shape of the graph.

(b) <u>a* value</u>:

Whereas a* value showed the increase with decrease in potato starch content and increase in finger millet flour as well as oat flour content (Fig. 4.5). In addition, the effect showed by WPI on a* value of extrudates was positive as value of a* also increase with increase in WPI content. Further interactions between F-P as well as F-W, O-W and P-W showed positive coefficient whereas the interaction between the F-O and O-P showed negative coefficient.

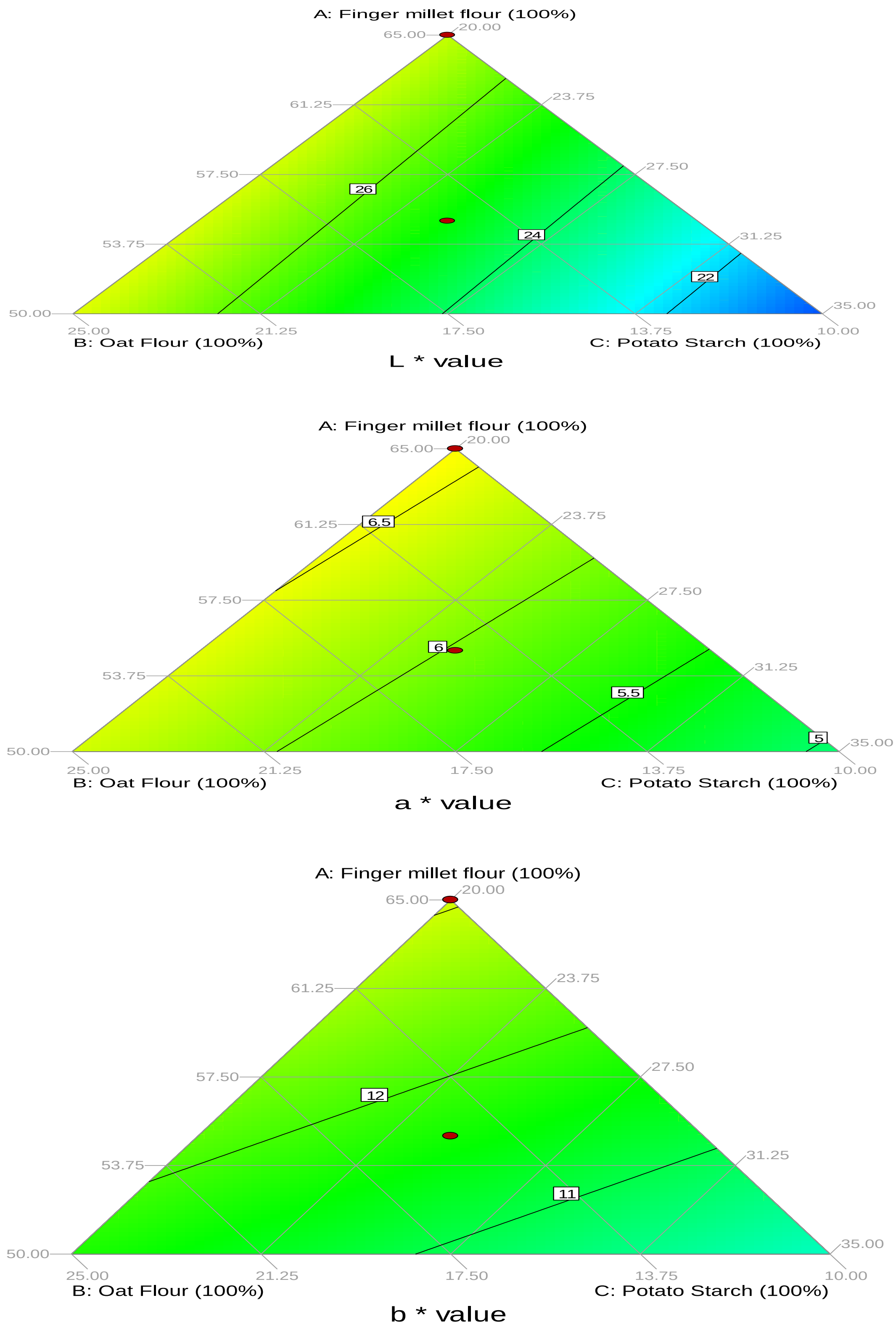

Figure 4.5 Contour graph for microwave roasted extrudate's L*, a* and b* value as a function of formulation mixture variable at 5% W proportion

4.3.3 Measurement of sensory quality attributes

Sensory tests are widely used in the food industry. Using sensory information as a part of a marketing decision has been given unprecedented attention. Being able to identify and quantitatively model the key drivers for a product's acceptance is now generally recognized as a core resource for any sensory program. Thus, combining sensory tests with new-product innovation can provide information to research and development people so they can develop more acceptable products. The importance of understanding consumer likes, dislikes and preferences are clearly known among sensory practitioners (Stone and Sidel, 2004).

Quality rating test can be included in rating methods. Quality judgment has been used primarily in the laboratory with small panels whose members usually have some specific experience or knowledge about the products under investigation, but this is not always easy to translate into the attitudes or behavior of consumers. When inexperienced judges are used with such a scale, evidence exists from studies at the Quartermaster Food Ss Container Institute (Schutz, 2006) that they rate according to what they like rather than for inherent quality differences. Here, the quality rating test gives the judges the freedom to give a mark about their own preference about the products to show the feeling of how much the customer like the products.

Whilst the nutritional properties of the products are a key consideration, the extrudates need to have satisfactory organoleptic properties, which are important for its acceptability. Dehghan-Shoar et al. (2010) reported that the acceptability of the extrudates depends mainly on the physical and sensory attributes, which are usually measured as density, expansion, taste and appearance. These properties are highly correlated to the number and size of air cells formed during extrusion (Morsy et al., 2015). The basic strength of descriptive statistics analysis is its ability to allow relationships between descriptive sensory and instrumental measurements to be determined.

Table 4.14 shows the degree of correlation (r) between instrumental measured values with sensorial evaluation results.

Furthermore:

- Positive values denote positive linear correlation;
- Negative values denote negative linear correlation;
- A value of 0 denotes no linear correlation;
- The closer the value is to 1 or –1, the stronger the linear correlation.

Correlation is an effect size and so we can verbally describe the strength of the correlation using the guide that Evans (1996) suggests for the absolute value of r:

- 0.00-0.19 “very weak”
- 0.20-0.39 “weak”
- 0.40-0.59 “moderate”
- 0.60-0.79 “strong”
- 0.80-1.00 “very strong”

Table 4.13 Type of correlation by considering effect of one variable on the another variable (Source: Tylor, 1990)

Type of correlation	Corresponding effects
Positive correlation	Other variable has a tendency to also increase
Negative correlation	Other variable has a tendency to decrease
No correlation	Other variable does not tend to either increase or decrease

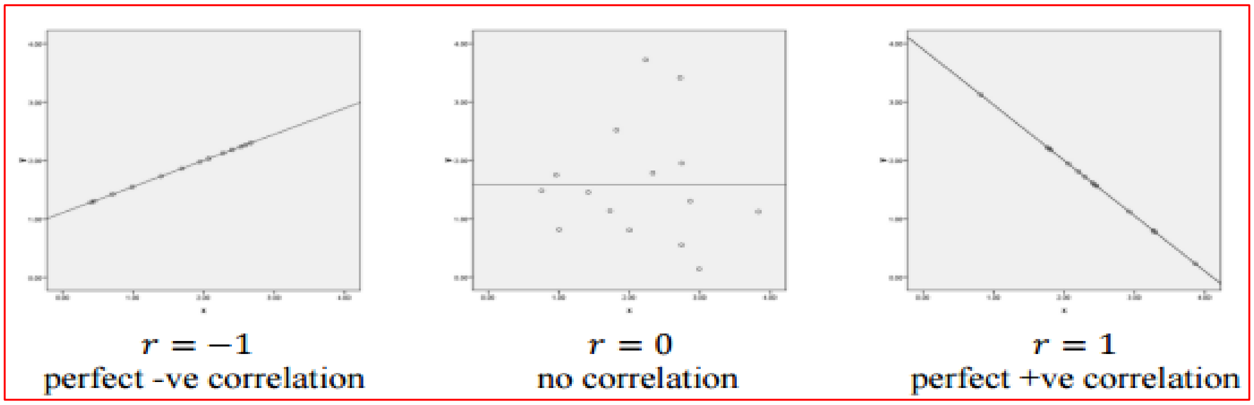

Figure 4.6 Samples correlation coefficient value's [graphical presentation of Table 4.11]

Table 4.14 Correlation coefficient analysis between instrumental and sensory responses

Instrumental response			Value of PEARSON'S correlation, r			
			Color	**Crispiness**	**Oiliness**	**Overall acceptability**
Color	**L***	**FR**	-0.40	-0.33	-0.01	-0.31
		MW	0.53	-0.04	0.04	0.06
	a*	**FR**	0.44	0.66	-0.24	0.75
		MW	0.53	-0.41	0.02	-0.09
	b*	**FR**	-0.44	-0.52	0.65	-0.27
		MW	0.57	-0.43	-0.03	-0.09
Rehydration ratio		**FR**	-0.22	-0.16	0.15	0.19
		MW	-0.27	-0.25	-0.65	-0.61
Expansion ratio		**FR**	0.62	0.06	-0.13	0.38
		MW	0.65	-0.19	0.03	0.15
Hardness		**FR**	-0.18	-0.08	0.50	0.15
		MW	0.15	0.75	0.85	0.77

Where '+' and '-' refer to their sign in the "Positive linear correlation" and "Negative linear correlation" respectively and 'FR' and 'MW' shows the extrudates that undergone either frying or microwave roasting respectively.

For both fried and microwave roasted extrudates, instrumental color value showed a high degree of positive correlation with sensory responses viz. color, crispiness, oiliness and overall acceptance quality (QRT). It means that the instrumentally measured color value of both the products (FR & MW) can be used as a quality monitoring criterion during post extrusion processing (frying and microwave cooking of extrudates). Furthermore a* value of fried samples has a strong positive correlation with overall acceptability of the samples (Table 4.14). This confirms that oil content plays a significant role in modification of texture of fried samples in favor of their acceptability by consumers like other fried products available in market.

Table 4.15 indicates the mean scores (presented after rounding off) of sensory evaluation. The result showed that all the extruded products prepared from composite flours were within the acceptable range, while the fried extruded product prepared from composite flour sample-9 had significantly better in color (7), crispiness (6), oiliness (6) and overall acceptability (7) with compared to other fried extrudates. In case of microwave roasted extrudates, the samples with desired sensory attributes was sample-19 as the scores for color, crispiness, oiliness and overall acceptability were 7, 6, 7 and 7 respectively.

Importantly, in case of microwave roasted extrudates, the impact of instrumentally measured hardness had found to be a very strong positive correlation with oiliness whereas it showed the strong positive correlation with crispiness and overall acceptability. While for the fried extrudates, it showed a moderate positive correlation with oiliness. Hence the positive correlation explains the phenomenon of increase in one variable due to rise of others'. Expansion ratio had a strong positive correlation with the sensory evaluated color of fried and microwave roasted samples. Rehydration ratio showed strong negative correlation with oiliness and overall acceptability for MW roasted extrudates. Means, negative correlation between variables usually gives an indication about the existence of an inverse relationship.

Table 4.15 Values of the sensory responses for fried and microwave roasted samples

Run	Quality Rating Test (QRT)							
	Fried extrudates				Microwave roasted extrudates			
	Color	Crispiness	Oiliness	Overall acceptability	Color	Crispiness	Oiliness	Overall acceptability
1	4	5	6	5	4	4	6	5
2	5	4	6	4	3	6	7	6
3	4	3	6	4	4	5	7	6
4	4	6	7	4	3	4	5	5
5	5	4	6	5	3	5	6	5
6	6	6	4	6	4	4	5	5
7	5	7	4	4	5	6	6	6
8	6	6	6	6	5	6	6	5
9	7	6	6	7	5	6	7	6
10	4	4	6	6	4	6	6	6
11	5	6	6	6	6	5	7	6
12	6	5	6	6	4	5	6	6
13	5	4	4	4	5	5	5	4
14	5	6	4	5	5	3	5	5
15	6	6	4	5	5	4	5	6
16	5	5	4	6	4	3	5	5
17	5	6	4	6	5	5	6	6
18	4	3	4	4	4	5	5	5
19	6	4	5	4	7	6	7	7
20	6	6	5	6	5	3	6	6

4.4 Conclusions

However, the oil content of fried snack available in the market is still a major concern for the consumers. And hence this works demonstrated the potential use of microwave roasting to reduce the oil content and make the product healthier. The hardness values for fried and microwave roasted extrudates ranged from 18.8 to 47.0 N and 14.8 to 39.11 N respectively. The expansion ratio for fried and microwave roasted products were in the range of 1.73 to 2.10 and 1.86 to 2.41 respectively. The RSM showed that the ER value increased with increase in potato starch content while it decreased with increase in oat flour and finger millet flour content.

Also color is one of the physical properties which determine the acceptability of the product. With an increase of frying time and temperature a* value increased. This is mainly because of reaction between amino acid groups of protein and sugar groups of starch with the influence of high temperature. Therefore color value and oil content of the fried samples were the two instrumental measurements which showed a strong positive correlation with sensorial taste values and can be used as a quality controlling variables in production of such type of product.

The addition of components enhanced the nutritional aspects of the samples viz. whey protein isolate had also showed the significant values with the other process variables. The consumer acceptance results reflect that overall quality score decreased with increase in W level. Although the mean values of sensory score for the extruded prepared up to 5% W are more close to 7.0, hence, keeping in view its nutritional value, it was considered most appropriate.

Sensory evaluation of the extruded product is the ultimate test to determine the acceptability of the product. The results demonstrated about the high degrees of correlation between instrumentally measured quality parameters of the extruded products with those from sensory tests. Further, the mean average sensory score for overall acceptability was found to be 5.15 for fried extrudates and 5.55 for the microwave roasted products. The samples were acceptable in the sensory analysis.

Table 4.16 Summarized information of the extrudate's formulation with desired characteristics

Snack product	Composition	Characteristics
Fried extrudates	F (65%), O (10%), P (20%), W (5%)	Overall acceptability: 7 (Very good) Expansion ratio: 1.73 Hardness: 32.27 N
Microwave roasted extrudates	F (70%), O (10%), P (20%), W (0%)	Overall acceptability: 7 (Very good) Expansion ratio: 1.87 Hardness: 36.52 N

Therefore, MW roasting was the preferred method for snack food development over the frying.

CHAPTER 5

GENERAL CONCLUSIONS AND FUTURE RECOMMENDATIONS

GENERAL CONCLUSIONS

1. Extrusion processing variables, viz. finger millet flour (F), oat flour (O), potato starch (P) and whey protein isolate (W) were found to have a significant ($p<0.05$) effect on extrudate's drying process, the final product's moisture content and water activity. All of the above extrusion process variables affected significantly ($p<0.05$) on drying time at extrudate water activity (aw) of 0.75. The result showed increase in the amount of whey protein isolate in the formulation significantly led to increase in extrudate's drying time ($p<0.05$), while, increase in potato starch proportions in the formulations significantly reduced the drying time to reach water activity of 0.75 and 18% (db).

2. The effect of twin screw extrusion process variables on the physical properties of dried extrudates were studied. All the linear terms of process variables and their interaction effects affected significantly on the various physical properties of dried extruded products. Higher potato starch content played a very important role in the increasing of ER and BD as well as to decrease BS. Whereas, a* value of dried extrudates found to be increased with higher proportion of oat flour content and lower proportion of potato starch content.

3. The expansion ratio for fried and microwave roasted products were in the range of 1.73 to 2.10 and 1.86 to 2.41 respectively. While it was in the range of 1.51-1.91 for the dried extrudates. Further, the linear terms of all the process variables had showed significant effect ($p < 0.01$) on expansion ratio values of dried, fried and microwave roasted extrudates. The RSM showed that the ER value increased with increase in potato starch content while it decreased with increase in oat flour and finger millet flour content.

4. The increase in oat and finger millet flour content increased hardness for both fried and microwave roasted products, whereas an increase in potato starch contents decreased the

hardness. Their respective hardness values ranged from 18.80 to 47.00 N and 14.80 to 39.11 N, respectively.

5. The regression equations obtained from the data of frying and microwave cooking were useful for the pre-determination of physical characteristics in order to tailor the process to get a product with the desired attributes.

6. The proximate protein content of dried extrudates varied between 6.40-19.15%.

RECOMMENDATIONS FOR FUTURE RESEARCH

This research has demonstrated several important findings. Meanwhile, it also showed some ideas of interest for future research and development, which could be summarized as follows:

1. The researcher can study the effect of alternative source for protein enrichment e.g. instead of whey protein isolate (W) we may have able to replace it with either soy protein or pea protein and similar other source of protein.

2. Similarly there will be possibility of replacing the starch source as the current study conducted with potato starch may be study after replacing with either corn starch or tapioca starch and other available sources.

3. Microwave roasting was successfully combined with extrusion in the current study. A more detailed study including how to develop a microwave roasted extrudates having similar profile of flavor and texture as the fried extrudates. To achieve this, we may need to develop the technique for spraying of oil on dried extrudates before microwave roasting and so that may leads to the desired final product with optimal color and flavor attributes as well as lesser oil uptake.

4. It might be interesting to study the use of seasoning oil during microwave roasting of extrudates. The foucs of interest will be to see the flavor development.

5. There is also a scope of to see the changes in flavor profile as a result of inclusion of various spices in the formulation mixture itself. So the probability of getting the extrudates with the desired flavor may be solved easily.

6. Different drying methods and drying conditions can be also evaluated as alternatives and optimized processes based on time, energy efficiency etc. could be identified.

7. The most interesting idea that caught my attention was to incorporate the flavored whey protein isolate (as in market you will easily find whey protein flavored with either vanilla or chocolate). So the extrudates may also have desired sensory attributes of the incorporated flavor.

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