

DEVELOPMENT OF LOW GLYCEMIC CEREAL BASED COLD EXTRUDATES

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DOCTOR OF PHILOSOPHY

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Food Technology

By

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DECLARATION

I, hereby declared that the presented work in the thesis entitled “**Development of low glycemic cereal based cold extrudates**” in fulfillment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of **Dr. Imdadul Hoque Mondal** working as **Assistant Professor**, in the **Department of Food Technology and Nutrition**, Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled “**Development of low glycemic cereal based cold extrudates**” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.) in Food Technology**, is a research work carried out by **Puja Nayyar** (Registration No.) **41800326**, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

Now a days, consumer demands for cereal-based products with low glycemic content and higher commercial qualities has been changed significantly. The present study aimed to develop low glycemic extruded pasta using buckwheat and chickpea flour by cold extrusion technology. Firstly, the extruded pasta was prepared with varied concentrations of buckwheat (50-100%) and chickpea (0-50%) by adopting a trial-and-error approach to characterize the cooking time, water uptake ratio, solid gruel loss, swelling index, volume expansion, texture, color and sensory parameters of the developed product. The results showed a significant enhancement in water uptake ratio, volume expansion and swelling index of extrudates from 2.00 - 4.23, 0.90 -1.11% and 18.48-22.67 respectively. The optimum characteristics were achieved for T₅ (60:40 buckwheat to chickpea ratio) i.e., addition of chickpea flour facilitated to reduce cooking time (4.28-3.71 mts.) and solid gruel loss (8.55-3.74%). Response Surface Methodology was employed to optimize the pasta formulations by adding xanthan gum and carboxymethylcellulose as additives. A Box-Behnken design with different concentrations of buckwheat (65-85%), chickpea (15-35%) and xanthan gum /carboxymethylcellulose (1.5-3.5%) was incorporated to optimize and characterize the pasta formulation based on multiple response parameters. By leveraging the best fit model, the optimization process targeted for highest resistant starch while lowest the glycemic load, glycemic index, solid gruel loss and cooking time using design expert software. The present study showed that the quadratic model provided the most accurate representation for all response variables. Analysis of proximate composition of xanthan gum and carboxymethyl cellulose incorporated extruded pasta was carried out and based on that, the former found to be the best with desired minimum glycemic index (29.74), glycemic load (4.10) and maximum resistant starch (9.09%). Further, the effects of packaging materials such as low-density polyethylene and aluminum laminates on the pasta extrudates were analyzed to determine their storage stability.

Keywords: Chickpea, buckwheat, low glycemic index, optimum characteristics, response surface analysis, carboxymethylcellulose, xanthan gum

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Place: Phagwara

Dated:

Puja Nayyar

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LIST OF ABBREVIATIONS USED

%	per cent
@	at the rate of
AACC	American Association of Cereal Chemists
AOAC	American Association of Analytical Chemists
BF	Buckwheat flour
ANOVA	Analysis of variance
C.D (p=0.05)	Critical difference at 5 per cent
cfu	Colony forming unit
GL	Glycemic load
RS	Resistant Starch
CT	Cooking time
SGL	Solid Gruel Loss
DPPH	2, 2-diphenyl-1-picrylhydrazyl
<i>et al.</i>	And others
Fig.	Figure
g	gram
GAE	Gallic acid equivalent
H₂SO₄	Sulphuric acid
hrs.	Hours
i.e.	That is
LDPE	Low Density Polyethylene
mg	Milligram
min	Minute
ml	Milliliter
mm	Millimeter
NaOH	Sodium hydroxide
No.	Number
°C	Degree Celsius
TPC	Total plate count

CHAPTER 1

INTRODUCTION

This chapter deals with the background of the cereal based extrudates. This chapter contains sub sections focusing on the background and applications of extrusion technology, pasta production, process optimization.

Food industry is contributing much in the overall economic progress of the country which completely relies on the agricultural sector for raw materials like fruits, vegetables, cereals, pulses etc. The food processing sector has witnessed significant growth over the years which include food processing, packaging and value addition as major components (Ebenezer and Savitha, 2023). In today's scenario, food being the most demanding and challenging sector in terms of value addition which is defined as the process of enhancing the nutritional profile, taste, shelf life and appeal of food products will remain in continuation in future as well because of the drastic changes in the economic status of people and more concern with their diet and nutrition. Value addition utilizes the advanced techniques like high pressure processing or freeze drying, extrusion technology for texture improvement, hike in nutrients percentage for adding value to the quality of food products. Among various value-added products of different food groups, especially in cereals and pulses, snacks and pasta are the most acceptable products in children and adults (Sule et al., 2023). The Indian Pasta market reached a value of US\$ 671.8 Million in 2021. On the other hand, market is expected to reach US\$ 1,754.5 Million by 2027, exhibiting a Compound Annual Growth Rate (CAGR) of 17.44% during 2022-27 (IMARC) (Market, 2022). The easiest and common technique used in the preparation of pasta using different ingredients is extrusion technology.

1.1 Background of Extrusion Technology and its applications

Sausage making was the initial use of extruders, which were invented in the 1870s. Pasta made from semolina flour and water was developed in the 1930's with the introduction of the single-screw extruder. Also, precooked dough was used to make ready-to-eat (RTE) cereals. In both cases, the shear force was shown to be negligible. Directly expanded curls were made in the 1930's and 1940's by use of extruders that utilized high shear pressures. Midway through the 1950's, the first patent pertaining to the use of twin-screw extrusion

technology was submitted. In the time after, extrusion technology saw tremendous growth and became increasingly important in the food processing industry (Ramachandra and Thejaswini, 2015). Ding et al. (2006) described extrusion technology which works at a high temperature for short duration is a step-wise process that involves continuous cooking, mixing, kneading, and shaping processing. The end result is a product with high quality attributes that is directly expanded. According to Rodriguez-Miranda et al. (2014), the extrusion process involves using a screw-barrel assembly to apply pressure and heat in order to mechanically shear and shape the material. Many structural and chemical changes occur in extruded goods, resulting in a wide variety of food items with different textures, forms, colors, flavors, and fragrances. Products with a low glycemic index (GI) have been developed by the use of extrusion cooking, a multi-functional, thermal process with a many step. It is a fresh and effective method of turning raw materials into finished goods with more value. Compared to other cooking methods, extrusion has a number of benefits, including a dramatic decrease in energy use and shorter processing periods, both of which lead to cheaper final goods. Cereals for babies, morning cereals, snacks, pastas, sauces, pet food, and meat products are just a few of the many items that are made utilizing food extruders. There is a huge opportunity to create a nutrient-dense extruded product by combining buckwheat flour with chick pea flour. This product will not only improve the health of the population, but it will also have desirable physical and sensory qualities, such as improved antioxidant properties and a low GI.

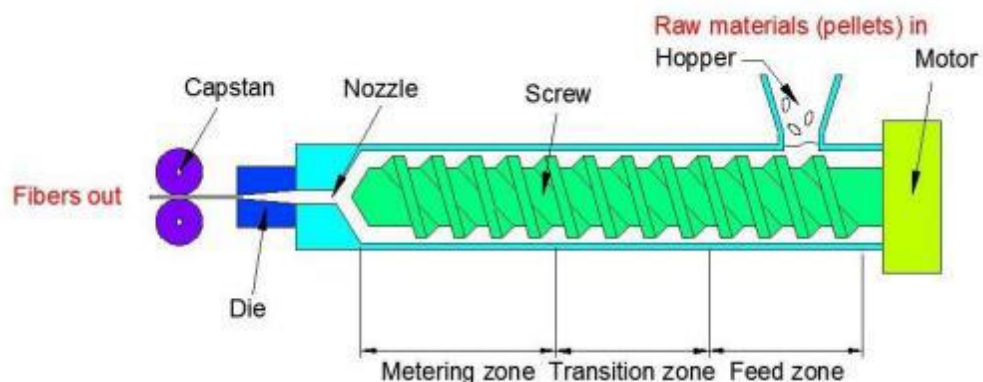


Fig. 1.1: Schematic representation of extruder and its main parts.

(Pasta and Noodle Maker, Model 16009 Make, Kent).

Two primary strategies are being utilized in the extensive situation of pasta product development. To begin, the manual method entails shaping the kneaded dough into the necessary forms using an extended thread-like structure, and then frying it to produce the end result. Second, the extrusion method incorporates several steps into a single unit. The ingredients are then sent through a hopper to the extruder, where unit activities including kneading, mixing, cooking, and shaping are performed. The extruder's end part can be fitted with a die to produce the required form. As an added bonus, this extrusion method is actually two distinct processes. The first, known as hot extrusion, keeps the temperature over 100 °C, while the second, cold extrusion, keeps the temperature below 100°C. While high-temperature extrusion cooking improves the created product's functional properties including swelling power, water solubility index, expansion ratio, crispness, and solubility, it drastically reduces the nutritional value of the finished product (Alam et al., 2015). Among the methods discussed before, cold extrusion is often considered the most eco-friendly and energy-efficient since it results in very little loss of nutrients. Its numerous benefits outweigh those of competing methods, such as manual and hot extrusion, including improved nutritional content preservation, simpler handling, and more precise process control leading to the desired product qualities. Manual processes, on the other hand, are laborious and time-consuming. On top of that, the lack of oversight throughout production guarantees low-quality results. For this reason, targeting pasta requires a more sophisticated strategy.

Pasta manufacturing is one area where the multi-faceted method of extrusion cooking is finding widespread usage in the food processing sector. One of the new ways to increase the value of agricultural products is by extrusion cooking. Cereal infant food, confectionery morning cereals, snacks, bakery items, etc., pet food, and pasta products are among the many food items that are mass-produced in factories. In light of this, the application of such a technology to the problem of creating pasta with added nutrients shows tremendous promise.

Extrusion cooking involves continuous pasta production and thereby ensuring its consistent quality and high output. As it is highly automated process thus, ensures the accuracy of dough consistency in the pasta preparation and its precise shaping. It also offers a choice of production of variety of snacks, breakfast cereals, pasta, supplementary foods and other textured foods. Extrusion process produces food products with low moisture content, which in turn helps the products to remain shelf stable and microbiologically safe for longer time

(Pathak and Kochhar, 2018) and also economically viable in food processing sector (Pansawat et al., 2008) to produce value added products of high nutritive value (Van-Hoan et al., 2010).

1.2 Cold Extrusion Technology in pasta production

Cold extrusion involves the process of shaping raw materials at a temperature below 100°C by applying compressive forces. Thus, it enables the development of pasta with varied choice of shapes with high precision and consistency. The dough is passed through an extruder where it is forced through dies with desired shapes. Cold extrusion act as a suitable way for the production of gluten free pasta by maintaining the integrity of dough. It also provides an efficient alternative of incorporating the choice of different ingredients such as spinach, amaranth, beetroot, and also allows the addition of flavours including herbs, spices in improving the taste of pasta.

1.3 An overview of pasta formulation

Pasta is typically made with wheat, a grain that is high in starch but low in protein, minerals, and other nutrients. Because it makes dough more elastic, gluten is the most crucial element for making pasta. Based on the work of Gallagher et al. (2004). It is crucial to replace gluten-containing ingredients with non-glutinous ones in order to make gluten-free food products. This is because people with celiac disease and diabetes cannot eat gluten-containing food products (Susanna and Prabhasankar, 2013). Nilusha et al. (2019) noted that legumes, yam, soy beans, corn, cassava, and sweet potato flour are commonly utilized to make composite flour for pasta.

Using a Brabender single screw extruder, Rangana et al. (2012) created pasta made from small millets and a combination of small millets and cassava flour. Pasta made from cereal bran, flour made from pearl millet (Yadav et al., 2014), and pasta made from flax seeds (ZarZycki et al., 2020) were all created by Kaur et al. (2012). The effects of adding plant proteins, such as bengal gram flour (15g/100g), mushroom powder (8g/100g), and defatted soya (9g/100g), to the created pasta were also investigated by Kaur et al. (2013). Pasta made with 25% chickpea flour had a lower glycemic index and more minerals than durum wheat pasta, according to research by Goni et al. (2003). To make a gluten-free spaghetti-like pasta,

Bouasla et al. (2017) combined pre-cooked rice pasta with flours from legumes such lentil, chickpeas, and yellow peas. Without affecting the minimal preparation time, this addition decreased the expansion ratio and lightness while increasing yellowness, firmness, and adhesiveness. The use of amaranth flour in pasta development reduced stickiness, which is an advantage for pasta products, according to Fiorda et al. (2013).

Pasta is typically made up of cereals and other flour-based ingredients. While there are many other kinds of cereals, wheat is by far the most popular. A high glycemic index is associated with pasta products that contain this component. However, the glycemic index of the product is also substantially raised by other grains. As a result, ingredients with lower glycemic index preferred and incorporated. To help those who suffer from glucose intolerance, it would be helpful for products to have a low glycemic index and high-quality standards. The glycemic index compares a test food-one that contains a typical quantity of carbs to a control food like glucose or white bread by measuring the incremental area under the blood glucose response curve following consumption of these carbs. Diabetic patients will get the most significant benefits from a low glycemic index diet. (Jenkins et al., 1994; Frost et al., 1999)

In contrast, pasta made with gluten flour would have a soft texture when cooked and a firm texture when dried, respectively, due to its low glycemic index. Buckwheat offers a possible alternative to traditional gluten and glycemic ingredient sources for pasta made utilizing the cold extrusion process.

1.4 Cereals and Pseudocereals in Pasta Production

Buckwheat (*Fagopyrum esculentum*) is a pseudocereal from the family Polygonaceae as it resembles cereal (Aufhammer, 2000). In Hindi and local language, buckwheat is named as “*Kutu Ka Aatta*”. It is an ancient crop of India and is commonly cultivated in the Himalayan region from Jammu and Kashmir to Arunachal Pradesh. It bears nutraceutical properties and due to which its incorporation into food products is gaining popularity in the development of healthy and nutritious food products. Among these, one is in the development of pasta with low glycemic index, being rich in proteins, minerals, vitamins and also good amount of dietary fibre, myo-inositol, d-chiro-inositol, fagopyritols, flavonoids and phytosterols (Zielenski, et al., 2001). Proteins present in buckwheat possess a higher biological value due to greater value of amino acids compared to other cereals (Jansen et al., 2017). With no gluten

content, buckwheat is recommended for celiac patients. As buckwheat is rich in terms of nutritional value, nutraceutical properties, resistant starch and because of its low glycemic index offers a good opportunity to use it as a main ingredient in the preparation of pasta extrudates for celiac as well as diabetic people. It is also helpful in reducing high blood pressure, lowering the cholesterol levels and preventing risk of cancer (Fabjan et al., 2003, Kim et al., 2004). Buckwheat is being used for the development of cookies, bread, pies, macaroni products and pancakes (Almedia, 1978). On the other hand, raw buckwheat groats have been reported to contain 33.5% resistant starch (Skrabanja and Kreft, 1998), because of which it is considered to be a good source to develop a value-added food product with low glycemic index. About 30% buckwheat flour in combination with other flours offers best results for the preparation of biscuits, girdle cakes, cracknuts, pancakes and noodles with low glycemic index (Levent and Bilgicli, 2011).

1.5 Proteins in pasta formulation.

In recent years, pulse's nutrient density and good protein quality have brought them widespread acclaim (Wani and Kumar, 2015; Boye et al., 2010). The amino acids lysine, aspartic acid, leucine, glutamic acid, and arginine are abundant in pulse proteins, but the amino acids methionine, cysteine, and tryptophan are insufficient (Boye et al., 2010). According to research conducted by Ha et al. (2014), consuming a diet high in pulses on a daily basis can reduce levels of blood cholesterol. The protein level of pulses used to make pasta is especially high; among legumes, soy flour has the most protein (Balasooriya and Wickramasinghe, 2018). There aren't enough of the amino acids lysine and threonine in 100% durum wheat pasta. Since chickpeas provide a lot of high-quality protein, using chickpea flour in pasta solves this problem (Fuad and Prabhasankar, 2010). The amino acid profile of chickpeas is well-rounded (Sabanis et al., 2006).

The chickpea, scientifically known as *Cicer arietinum* L., is an important pulse crop that ranks third in importance. It is chock-full of protein, minerals, fiber, vitamins, and has a low glycemic index. The kabuli and desi varieties of chickpeas are the most common. Among pulse crops, chickpeas have the highest protein contents and the most calories per 100 grams. According to the FAO in 2019. Clinical and pre-clinical research suggests that chickpeas have anti-inflammatory, antifungal, and antioxidant properties.

In terms of decreasing glucose levels, cardiovascular illnesses, hypertension, cancer, and cholesterol, chickpea consumption has favorable effects (Sharma et al., 2017). The creation of affordable food products that promote excellent health can make greater use of these beneficial impacts. Meng et al. (2010) Protein (19.0%), carbohydrates (61.0%), and fiber (17.0%) are all abundant in this fundamental bean. Yukanti et al. (2012) claims that chickpeas have the highest protein quality of any pulse, and their hydrolysates contain promising bioactive components. According to Jukanti et al. (2012), it is also rich in minerals particularly potassium, and vitamins, including folate, riboflavin, thiamin, niacin. There is some evidence that the carbohydrate content of chickpeas has a low glycemic response when it comes to nutrition. Chickpeas are similar to wheat and rice in that they are high in dietary fiber and have a low glycemic index, but they also include a lot of minerals like potassium, sodium, calcium, magnesium, copper, iron, and zinc (Esimat et al., 2010). The nutritional profile of the extruded food was boosted by using chickpea (Leonard et al., 2020). Research investigating the nutritional, functional, and physical characteristics of extruded chickpea-based products also lends credence to the beneficial impacts of its inclusion (Wang et al., 2008,). A perfect example of this would be the creation of chickpea snacks that are immediately ready to eat and made using the extrusion cooking method.

1.6 Role of thickening in pasta preparation

Addressing global concerns, promoting sustainable practices, minimizing waste, and ensuring access to safe and nutritious food for all are all critical components of the present food picture. Pasta made from a combination of grains has been the subject of multiple investigations into its creation and characterization, as far as we are aware. To get high-quality pasta, though, it's essential to add the right ingredients. (Mir et al., 2015; Singh et al., 2015; Hojjatoleslami and Azizi, 2015; Herranz et al., 2016) Research on the use of gums such as xanthan gum, C.M.C, tragacanth, and others to regulate the moisture content, texture, and porosity of gluten-free pasta products has been conducted. Thickeners and gums like guar gum and C.M.C aid in the development of healthy pasta by thickening, gelling, enhancing water holding capacity, texture, and overall acceptability (Gallagher et., 2004). Sudha and Leelavathi (2012) state that adding fiber-rich foods to pasta increases its

nutritional value. These seasonings are essential for gluten-free pasta to have the same mouthfeel and satisfying texture as regular pasta. A number of process variables, including the concentrations of ingredients (buckwheat, chickpea, and xanthan gum), have a substantial impact on pasta quality parameters such as glycemic index, resistant starch, cooking time, solid gruel loss, and nutritional load. A couple of hydrocolloids that find extensive use in food applications are carboxymethyl cellulose (C.M.C) and xanthan gum (XG). The cellulose backbone of both has substituents that extend from the main chain and β (1, 4)-D-glucose units. According to Asiamah et al. (2012), xanthan gum has a carboxymethyl group substituent while C.M.C has a trisaccharide side chain substituent.

An increase in the consumption of foods with a low GI has been proposed by FAO/WHO expert consultation (FAO/WHO, 1998). Diabetes patients, healthy people in general and diabetic patients in particular have all shown a favorable association between a low GI diet and health benefits (Frost et al., 1999; Jenkins et al., 1994). Pasta made with low gluten flour has a tendency to become too sticky and soft while cooked, and a firm texture when dried. Adding food additives can help with this problem. In order for foods to have desirable properties, certain additives are essential. The complex hydrophilic carbs known as gums are composed of hundreds of monosaccharide units and are renowned for their ability to increase water absorption, texture, and shelf life.

1.7 Optimization process

Optimization of these parameters is essential for the successful development of cold extruded pasta with low glycemic index. Response surface methodology (RSM) has proven to be a valuable tool for optimizing process parameters in various food formulations. Several studies have applied RSM to develop non-wheat pasta, reduce gluten content in gluten-free bakery products, and investigate the effect of various ingredients and cooking times on food properties (Yadav et al., 2012; Huang, Knight and Goad, 2001; Shirashoji et al., 2006, 2010; Motevalizadeh et al., 2018)

Application of RSM in the context of cold extrusion technology for low glycemic index pasta products remains an unexplored area of research. However, none of the studies have

attempted to explore buckwheat and chickpea flours for pasta production with low GI and high protein content. The study thus aims to develop a low GI extrudates from a blend of buckwheat and chickpea flour. Besides, keeping in view their positive effects on overall nutritional profile as well as physical characteristics, the study was made with the incorporation of two additives such as xanthan gum (XG) and carboxymethyl cellulose (C.M.C) in the development of low glycemic pasta extrudates.

CHAPTER 2

REVIEW OF LITERATURE

This chapter elaborates details state of art under the following headings:

The terms "pasta" and "noodles" are often used interchangeably to describe similar dishes. However, it's more accurate to use "noodles" for East Asian cuisine and "pasta" for Mediterranean, particularly Italian, dishes. Despite their similar shapes, these foods differ significantly in taste, ingredients, and preparation methods, justifying the distinct terminology (Lierheimer et al., 2022). It is the generic term for variety of flour-based noodles and is regarded as a product with low G.I (Bjork et al., 2000). It is a staple diet of Indian cuisine and is now popular throughout the world. More than 600 pasta shapes are available out of which, the most popular are spaghetti (thin strings) and macaroni (tubes or cylinders) and are categorized into two basic styles: (1) dried and (2) fresh. Pasta is generally cooked by boiling.

2.1 Optimization of pasta formulation using hot and cold extrusion technology

Rafiq et al. (2017) investigated how feed moisture levels (28%, 32%, and 36%), barrel temperatures (30°C, 40°C, 50°C, 70°C, 90°C, and 110°C), and the percentage of brown rice (10%, 20%, and 30%) affect pasta quality using a twin-screw extruder. Their results indicated that gelatinization levels were negatively correlated with legumes but positively correlated with feed moisture and barrel temperature. They also found a positive correlation between these factors and the pasta's water absorption capacity. Conversely, an increase in the feed moisture-to-brown rice ratio was linked to higher cooking losses, while the increase in barrel temperature led to decreased cooking losses.

In the food processing industry, roller, piston, and screw extruders are commonly used, with screw extruders being the most prevalent (Alam et al., 2015). These extruders process dough-like raw materials through a heated barrel, where friction and the mechanical energy from rotating screws elevate the temperature. Screw extruders are categorized into single-screw and twin-screw models. Single-screw extruders, which have feeding, transition, and melting/degradation sections are ideal for materials with high friction coefficients but may require pre-mixing due to limited mixing capabilities.

In contrast, twin-screw extruders, despite their more complex design, are favored for their versatility and ability to handle thick or challenging materials. They come in co-rotating and counter-rotating types, with co-rotating models being preferred for their efficiency in mixing and conveying materials (Moscicki et al., 2011).

Cold extrusion, used in pasta production, involves combining and shaping ingredients at temperatures below 40-50°C. However, research suggests that high-temperature extrusion methods can expedite pasta cooking (Rafiq et al., 2017). While single-screw extruders are typically used in pasta making, twin-screw extruders are also applicable.

Rangana (2014) explored the development of cold-extruded pasta and vermicelli using various types of small millets which includes foxtail, kodo, proso, barnyard and little for the formulation in product development included a 50:40:10 ratio of millet flour to wheat and soy flours. Sensory evaluations suggested the foxtail millet kheer as the extremely liked and attained the top scores whereas the kodo and proso millet kheers attained less scores as compared to foxtail millet. Millet-based pasta masalas were well-received, with proso millet pasta masala and kodo millet being particularly favored. Nutritional analysis showed minimal difference in vermicelli composition before and after storage, with quality maintained for up to two months in either 300 or 400 PE gauge packaging.

Pardeshi et al. (2013) investigated the production of cold-extruded mung (*Vigna radiata* L.) nuggets. A pasta machine was used to extrude a Mung flour and wheat flour mixture, which was then steam-cooked and dried. The study found that optimal conditions included 24% wheat, 36.28% initial moisture, 6 mts. of steaming, and 6 hours of drying at 60±2°C, resulting in a final moisture content of 7.73%. These mung nuggets, requiring less processing time than traditional wadi, could also be soaked and stored at 30°C for up to 114 days using metalized polyester packaging.

Wojtowicz and Moscicki (2011) produced precooked pasta by blending wheat flour with wheat bran using a single-screw extruder. They explored how varying screw speeds and bran addition rates affected the microstructure and texture of the pasta. The barrel temperatures during extrusion were adjusted from 85°C at the input to 75°C at the output. They used screw speeds of 60, 80, 100, and 120 rpm, and bran addition rates

of 5%, 10%, 15%, 20%, and 25%. Their findings revealed that both screw speed and bran content influenced pasta quality. Lower screw speeds led to the presence of ungelatinized starch granules and unconverted bran, while higher speeds caused the breakdown of bran cell walls. Increased bran content and lower screw speeds resulted in pasta with higher stickiness and lower hardness, as well as darker color, as indicated by reduced L* values.

El-hady and Habiba (2003) studied about various antinutritional factors and protein digestibility for meals made from peas, chickpeas, faba beans, and kidney beans during extrusion technology which includes soaking of meals in water for sixteen hours, and then subjected to extrusion with barrel temperatures between 140°C-180 °C at feed moisture ranges of 18% and 22%.

Baik et al. (2004) examined the relationship between extrudate characteristics and screw speed in extruders. They found that expansion indices and water absorption indices (WAI's) of extrudates were directly related to screw speeds. As the feed rate increased from 89-96 g/min, the expansion indices of regular and waxy barley decreased, resulting in harder extrudates.

Ding et al. (2006) revealed that the density and hardness of wheat extrudates decreased slightly at screw speeds (189 to 320 rpm)

The investigations made by Chaiyakul et al. (2009) clearly explained the impact of extrusion variables such as moisture content, protein concentration, and temperature on the physical and chemical attributes of rice-based snacks rich in proteins and gluten.

Singh et al. (2007) examined the effects of different feed moisture levels (18% - 24%), extrusion temperatures (130°C to 170°C), and pea grit ratios (0-30%) with respect to extrusion behavior and properties of rice grits. The factors such as density, water solubility index, extruder die pressure, expansion ratio, and specific energy consumption using second-order polynomial models were determined to analyze the relationship between these variables and product qualities.

Using a single-screw extruder, Duarte et al. (2009) explored the impact of moisture, soybean husk and temperature on the production of maize extrudates. For temperature

(100°C - 200°C), soybean husk content (0% to 40%), and screw speed (100 to 200 rpm), variation of different parameters viz. cold viscosity, peak value, breakdown, setback, sectional expansion index (SEI), and specific mechanical energy (SME) has been investigated. The analysis concluded that the interactions between temperature and soybean hull content increased breakdown and decreased setback, while SME and SEI were also reduced.

Investigations made by Yu et al. (2011) on the chemical and physical properties of waste of mung bean with respect to extrusion parameters using a single-screw extruder with Tainan No.5 mung beans, they varied screw speeds (20–40 rpm) and barrel temperatures (90–100°C). They analyzed physical characteristics viz. such as water activity, moisture content, color attributes, thermal properties, and resistant starch concentration. Results showed that neither extrusion nor storage notably affected water activity or moisture content, although color (L value) decreased with longer storage.

Yu et al. (2012) explored co-rotating twin-screw extruder for the development of maize and soy protein isolate based extrudates. Their findings concluded that the extrusion parameters showed tremendous effects on the expansion ratio, density, rehydration ratio, breaking strength, and color, especially with feed moisture being the most significant effect as far as the physical properties are concerned.

The studies made by Duizer et al. (1998) assessed the sensory characteristics of food by analyzing acoustic signals recorded during biting into samples. Using Kolmogorov dimension and fast Fourier transform, they found that foods with lower moisture and water activity had a crispier texture. Fourier transforms showed peaks in the 1-2 KHz and 6-7 KHz bands, and fractal analysis of time-amplitude curves correlated sensory attributes such as crunchiness and sharpness with fractal dimensions.

Katta et al. (1999) applied extrusion technology on maize grits injected with fumonisin B1 (FB1) using a co-rotating twin-screw extruder and tested with different temperatures (140-200°C) at different screw speeds being lowest 40, 80, 120, and highest 160 rpm. Their research, using HPLC to measure FB1 levels, showed that both barrel temperature and screw speed significantly affected FB1 reduction. FB1 levels decreased by 34% to

95%, with greater reductions at lower screw speeds and higher temperatures, regardless of product expansion or color.

Sacchetti et al. (2004) developed snack bread by extruding a chestnut flour and rice mixture. The extruded dough was formed into pellets and toasted. The functional and physical attributes of extrudates with respect to extrusion temperature on color, moisture content, water absorption index, water solubility index and water-holding capacity were assessed. Despite high sugar content in chestnut flour preventing expansion and gelatinization, increasing the extrusion temperature and chestnut flour percentage accelerated browning.

Ding et al. (2005) analyzed how extrusion parameters influenced the sensory and physicochemical properties of enlarged rice snacks. Feed moisture content, feed rate, barrel temperature and screw speed were mainly undertaken as the independent variables. They concluded that higher feed rates led to harder extrudates with lower water solubility index (WSI) and greater expansion. Extrudates from higher moisture feeds were harder, less crispy, and had lower expansion and WSI. Increasing barrel temperature improved crispness, expansion, and density, but did not significantly affect sensory attributes or physicochemical properties with varying screw speeds.

Veronica et al. (2006) investigated the effects of adding 10%, 20%, and 30% protein-dense soybeans (PDS) to corn snacks. They assessed the snacks physical, chemical, and sensory attributes, including hardness, density, color, texture, brittleness, and breaking strength. While the addition of PDS improved the chemical properties of the snacks, it negatively impacted their physical and sensory characteristics. Snacks with 30% PDS had protein levels ranging from 9.3% (with just maize) to 19.3% (with 30% soybeans). The sensory evaluation revealed that snacks with 30% PDS were less appealing, harder to break, and lacked desirable puffiness and crispiness compared to those with lower PDS levels. However, snacks with up to 20% PDS still retained some appeal.

Altan et al. (2008) observed the extrusion of blends of tomato pomace and barley flour using a corrugated twin-screw extruder. They analyzed twenty combinations with changing die temperature (140–160 °C), tomato pomace (2–10%) and screw speed (150–200 rpm). The study emphasized on parameters such as specific mechanical

energy, die melt temperature, and die pressure. Responses included bulk density, texture, color, solubility and water absorption index, and expansion. Sensory evaluation briefed that extrudates containing 2% or 10% tomato pomace and extruded at 200 rpm and 160°C attained the best color, texture, flavor, and overall acceptability.

Ainsworth et al. (2007) explored how varying screw speeds (100-300 rpm) and brewers waste grain (BSG) percentages (0-30%) influenced various qualities of extruded snack foods. They measured a range of nutritional, physical, chemical, and structural parameters, including in vitro protein digestibility, resistant starch, color, and specific mechanical energy. The study found that higher screw speeds reduced hardness, but the inclusion of BSG resulted in decreased expansion and increased resistant starch content. BSG also led to a darker color in the samples, though it did not significantly affect other parameters such as total antioxidant capacity or total phenolic content.

Stojceska et al. (2008) studied the incorporation of cauliflower scraps into expanded snack products. They added dried and milled cauliflower trimmings in amounts ranging from 5% to 20% and used a twin-screw extruder with specific parameters such as a solid feed rate (20-25 kg/h), screw speed (250-350 rpm), water feed (9-11%), and processing temperature between 80°C and 120°C. Increased protein and dietary fiber content of the extrudates is only because of the addition of cauliflower but results in reduced expansion and in vitro digestibility. Sensory testing suggested that upto 10% cauliflower could be used without significantly affecting consumer appeal.

Stojceska et al. (2009) investigated how different feed moisture levels (12-17%) impacted the nutritional and physical properties of extruded products made from wheat flour and maize starch. The study included formulations with 10% beer waste grain (BSG) or red cabbage (RC) trimmings. at constant parameters being feed rate 25 kg/h, barrel temperatures 80-120°C and screw speed 200 rpm. Increasing moisture content led to higher total dietary fiber (TDF) in all extrudates. The WRC products had lower TDF compared to CBSG, CRC, and WBSG samples. Extrusion also enhanced antioxidant capacity and phenolic compounds, with feed moisture influencing expansion ratio, hardness, bulk density, and other characteristics.

Anton et al. (2009) explored extrudates made from blends of corn starch, navy bean and red bean flours (15%, 30%, and 45%). Keeping extrusion conditions constant (160°C, 22% moisture, and 150 rpm), they found that bean-flour extrudates had higher density and toughness than those made from corn starch alone. At 30% bean flour, extrudates had improved protein content and antioxidant activity, though extrusion slightly reduced total phenols and antioxidant activity. Bean-flour extrudates showed lower levels of phytic acid and trypsin inhibitors, indicating they are safe for consumption.

Meng et al. (2010) evaluated chickpea flour snacks by varying feed moisture from 16 to 18%, screw speeds 250 to 320 rpm, and barrel temperatures 150 to 170°C using response surface methodology (RSM). The study assessed physical properties such as expansion, bulk density, hardness, die pressure, motor torque, and specific mechanical energy (SME). The findings showed that all three factors significantly affected the extruder responses and product qualities. Optimal conditions included low bulk density and hardness, high expansion ratio, and medium to high barrel temperatures.

Brennan et al. (2011) explained the integration of bioactive compounds into extruded foods, highlighting that factors like shear, temperature, residence time, and water content affect the concentration and stability of bioactive compounds. The review discussed how extrusion processing impacts bioactive molecules, including antioxidants, polyphenols, anthocyanins, and isoflavones, and explored the factors influencing their concentration and stability in extruded products.

Licata et al. (2014) explored the potential of producing healthy foods by extruding a sorghum-maize composite flour using high-pressure and high-temperature conditions. They employed a factorial experimental design to examine the impact of several factors: the proportion of sorghum in the dry mix (ranging from 15-60%), barrel temperature 120-150 °C, barrel moisture 21.4-25.8%, screw speed 250-450 rpm and input rate 2.3-6.8 kg/h. The study assessed the extrudates for expansion ratio, density, protein digestibility, antioxidant capacity, phenolic content, and slowly digestible starch (SDS). Findings indicated that SDS levels increased with higher sorghum content but decreased with elevated barrel temperatures. Higher sorghum concentrations

enhanced antioxidant capacity and total phenolic content, but protein digestibility was inversely related to sorghum content and improved with higher barrel temperatures. While extrudate density improved with increased moisture content, it decreased with higher barrel temperatures and input rates. Key factors influencing extrudate quality included the total moisture in the barrel, final barrel temperature, and sorghum percentage in the dry mix.

Hirth et al. (2014) observed the retention of bioactive components in bilberries after extrusion cooking. Using a twin-screw extruder, they processed a mixture of 2% bilberry extract and maize starch. The study examined how screw speed, moisture level and barrel temperature affected anthocyanin retention, antioxidant activity and total phenols. The results revealed that antioxidant activity and total phenolics remained stable during extrusion. Optimal anthocyanin retention occurred under the following conditions: minimal moisture content (28%, $c/c_0 = 0.90$), maximum flow rate (30 kg/h for 360 rpm and $c/c_0 = 0.77$), and minimal barrel temperature (100°C, $c/c_0 = 0.82$). Increasing the flow rate improved anthocyanin retention for highest screw speed 720 rpm, while the addition of a flow channel reduced retention due to extended exposure time. The comparison of extrusion cooking and offline heating of bilberry extract solutions affirmed anthocyanin degradation was influenced by mechanical energy and moisture content. Extruded samples retained up to 82% of their anthocyanins even after 40 months of storage. The study concluded that extrusion cooking can be controlled to effectively incorporate antioxidants and phenolics, including anthocyanins, into products.

2.2 Effects of extrusion conditions on different variables.

The studies made by Gimenez et al. (2013) briefed the sensory and physical attributes of spaghetti made from corn and broad beans with respect to the impact of extrusion parameters. They varied the moisture levels of the pasta dough (28%, 31%, and 34%) and extruded it at temperatures of 80, 90, and 100°C. Key factors assessed included edema, cooking loss, water absorption, hardness, and adhesiveness. The study found that higher extrusion temperatures and increased dough moisture levels led to greater expansion of the spaghetti and reduced cooking loss. At 100°C, the maximum water

absorption capacity of the spaghetti dough was found at moisture levels of 28% or 31%. Sensory evaluations revealed that spaghetti extruded at higher temperature and lower moisture content received the best ratings for firmness and stickiness from trained panelists.

2.3 Effects of ingredients on cooking parameters.

Pasta is a staple food enjoyed globally, traditionally made from coarse semolina derived from durum wheat mixed with water. High-quality pasta relies on optimal gluten levels and premium durum wheat, which is crucial given that durum wheat contributes to less than 5% of the global wheat production (Nilusha et al., 2019). Due to rising pasta demand and the high cost of durum wheat, there is a growing interest in alternative ingredients.

Bhattacharya (1997) investigated a 31 mm diameter co-rotating twin-screw extruder using a 1:5 dry basis ratio of rice and *Vinca radiata L.* for green gram. The study focused on how varying screw speeds (100-400 rpm) and barrel temperatures (100-175°C) affected the properties of extrudates.

Extrusion temperature significantly influences pasta quality, particularly in terms of cooking losses. An increase in the extrusion cylinder temperature from 35°C to 70°C can boost cooking losses by around 250%. This is because high temperatures impair the semolina proteins' ability to form a network that retains starch granules, making the dough unsuitable for cooking. Enhancing hydration from 44% to 48% and increasing screw rotation speed from 15 to 30 rpm at higher extrusion temperatures (approximately 70°C) positively affects the pasta's quality (Bresciani et al., 2022).

De la Peña and Manthey (2017) examined the extrusion properties and cooking outcomes of refined and wholemeal semolina, flaxseed flour, and their mixtures, varying the hydration levels from 30% to 34%. Their results indicated that increasing moisture levels led to a decrease in extrusion pressure and specific mechanical energy (SME).

Jayasena et al. (2012) replaced durum semolina with lupin flour at various levels (0%, 10%, 20%, 30%, 40%, and 50%). They observed that incorporating up to 30% lupin

flour did not affect the optimal cooking time (OCT). However, pastas with 40% or 50% lupin flour exhibited a notable increase in OCT. The cooking loss remained consistent across all lupin flour concentrations. Color analysis showed differences in L* and b* values for pasta with more than 20% lupin flour. Generally, pastas with up to 20% lupin flour were well-received for their color, appearance, taste, and texture, but acceptance declined with higher lupin flour levels.

Soboba et al. (2015) explored how varying the proportion of wheat bran in relation to wheat semolina affected pasta quality during industrial production. While pasta with 20% wheat bran had lower cooking loss, higher bran concentrations led to increased cooking loss and a less favorable sensory profile. The reference sample made from durum wheat flour scored highest for brightness, glossiness, and consistent semi-transparent color, though the bran-enriched pasta was perceived as having an unpleasant aftertaste. Higher fiber content resulted in tougher pasta.

Marconi et al. (2002) found that *Triticum spelta* L. wheat, or spelt, possess similar technical and rheological properties as that of durum wheat, making it a viable alternative for nutritious and flavorful pasta production. Their research showed that spelt flour can produce high-quality pasta if the protein content exceeds 13.5% (spelt grains contain about 15% protein) and if high drying temperatures are used, ensuring optimal cooking results.

Manthey et al. (2004) found that incorporating up to 30% buckwheat bran flour into spaghetti recipes reduced the ideal cooking time. This is attributed to the buckwheat bran disrupting the gluten network and decreasing the pasta's density, which in turn increased water absorption and shortened cooking times. Properly cooked spaghetti retains its mechanical properties, and the optimal cooking point is often indicated by its texture and firmness.

Bhuvaneswari et al. (2005) explored the extrusion and pasta-making characteristics of *Triticum dicoccum* wheat varieties. Known for its β -carotene content, high protein, and dietary fiber, as well as a low glycemic index, *Triticum dicoccum* offers notable nutritional advantages. However, its commercial use is limited due to the challenges of dehulling and its less appealing reddish color, which can deter consumers. Despite this,

Triticum dicoccum vermicelli displays qualities similar to durum wheat vermicelli, such as firmness and low solubility, though it differs in color due to its β -carotene content. Research suggests that protein and ash levels in *Triticum dicoccum* are positively correlated with the swelling capacity of vermicelli.

Shogren et al. (2006) demonstrated that spaghetti could be made with up to 35% soy flour while still maintaining good taste and texture. This combination enhances the protein and lysine content in the pasta, leading to improved flavor and reduced cooking times for products containing both wheat and soy.

Chillo et al. (2008) characterized spaghetti prepared from blends of durum wheat bran and buckwheat flour. Spaghetti made with these ingredients exhibited a darker color compared to that made with durum semolina alone. The presence of dietary fiber, which contributes to the pasta's darker hue, is generally perceived as beneficial for health, and consumers are often willing to accept this color change.

2.4 Effect of Dietary fibre in extrusion

Padalino et al. (2014) described the effects of various fibers on spaghetti production. They found that adding pea flour decreased the swelling index and increased hardness, contrary to the findings of Tudorica et al. (2002). This resulted in a less desirable color and odor, which negatively impacted the product's quality. To improve sensory attributes such as color and flavor, guar gum was added. The addition of guar gum, combined with pea flour, resulted in a lower glycemic index due to increased soluble fiber and reduced starch digestibility compared to the control sample.

Piwinska et al. (2016) studied how oat β -glucan fiber affected pasta's physical properties and cooking performance. Pasta with varying concentrations of oat β -glucan fiber (4% to 20%) maintained consistent optimal cooking times. However, fiber-rich pasta absorbed more water compared to the fiber-free version. The swelling index remained unchanged with fiber levels up to 8% but increased significantly at higher concentrations. The oat β -glucan fiber also affected the pasta's color across all tested levels.

Tudorica et al. (2002) explored the benefits and drawbacks of incorporating different dietary fibers into pasta. They tested recipes with varying levels of pea fiber (7.5%, 10%, 12.5%, and 15%), inulin (7.5%, 10%, 12.5%, and 15%), and guar gum (3%, 5%, 7%, and 10%), as well as a control without fiber. Guar gum increased the swelling index by 10%, while other fibers had minimal impact. Pasta made with pea fiber or inulin showed increased cooking time and higher solid losses due to disrupted protein networks. Adding 3% guar gum reduced cooking and solid losses, while 5%, 7%, and 10% levels maintained these losses similar to the control. For a softer pasta texture, adding pea fiber (7.5% to 15%) or guar gum (10%) was recommended, with the control pasta being more flexible compared to those with inulin or guar gum.

2.5 Ready to eat snacks and their properties using different ingredients in extrusion.

Pawar et al. (2009) developed ready-to-eat extruded snacks by processing blends of corn grits, rice, and bean malt through a single-screw dry extruder at ratios of 8:1:1 and 7:2:1. They evaluated these snacks for their chemical composition, physical characteristics, and sensory attributes. The analysis revealed that the snacks contained between 10.1% and 12.0% protein, 0.8% to 1% fat, and 3.0% to 3.2% ash. The expansion ratios of the snacks ranged from 1.72 to 1.77, and their densities ranged from 1.25 to 1.40 g/cm³. The snacks were well-cooked, evenly shaped, and appropriately sized. Sensory evaluations indicated that snacks incorporating legume malt were preferred over those without it, with a particular preference for snacks made with a 7:2:1 ratio of green gram malt compared to moth bean malt.

Lazou et al. (2010) studied the functional attributes of maize and corn-lentil blended extrudates with varying extrusion conditions. The study varied extrusion temperatures from 170°C to 230°C, feed moisture percentages from 13% to 19% (wet basis), and feed rates from 2.5 to 6.8 kg/h. The lentil-to-corn flour ratios ranged from 10% to 50%. Results showed that the extrusion parameters significantly impacted various functional properties of the extrudates.

Studies made by Cavada et al. (2011) on the influencing effects during incorporation of legumes (wild Lathyrus) to whole maize and brown rice during extrusion. Incorporating beans into the rice and maize mixtures reduced growth rate and increased solubility. Even a 15% substitution with beans led to notable improvements in nutritional content, including higher levels of minerals, dietary fiber, and protein. Protein digestibility ranged from 82% to 84%, and the availability of iron and zinc increased from 6.4% to 12.1% and 10% to 18.6%, respectively. These findings highlight that adding wild legumes can enhance the nutritional profile of extruded products while maintaining their essential physical attributes.

Dandamrongrak et al. (2011) conducted experiments at Naresuan University in Thailand using a laboratory-scale single-screw extruder to measure the impact of extrusion conditions on the parameters especially expansion ratio of mung bean and jasmine rice extrudates. They adjusted initial moisture levels and grain sizes, categorizing the grains into three groups based on particle size using 12 and 14 mesh screens. The barrel temperature was maintained at 190°C throughout the tests. The researchers used a response surface methodology to identify the optimal particle size and moisture content ranges for maximizing the expansion ratio of the extruded products. Their study aimed to optimize these variables to achieve the best expansion ratio for mung bean and jasmine rice snacks.

2.6 Packaging and Storability of pasta formulation

Singh et al. (2000) investigated the moisture absorption characteristics of developed biscuits stored in different packaging materials. Biscuits stored in polypropylene bags absorbed less moisture compared to those in laminated pouches over a 60-day period. This comparison highlighted how different storage conditions affected moisture absorption in soy-fortified biscuits, with those in laminated pouches showing greater moisture uptake.

Selvaraj et al. (2002) investigated the moisture content of biscuits containing finger millet flour, stored under accelerated conditions of 90% relative humidity and 38°C. Biscuits in poly-laminate packs reached an essential moisture content of 5% in about 75 days, whereas those in double polypropylene pouches achieved this level in 50 days.

Additionally, biscuits made with finger millet flour had a lower initial extractable fat content (0.61%) compared to control biscuits (0.77%).

Nasir et al. (2004) analyzed the impact of storage on the nutritional and microbial aspects of wheat flour. Over a 60-day period, significant decreases were observed in moisture content (11.43%), crude protein (11.49%), total ash (1.70%), total iron (41.26%), and total fat (11.49%). Conversely, mold growth increased from 152 to 926 colonies, while nitrogen-free extract and crude fiber levels rose from 70.01% to 70.80% and 1.71% to 2.49%, respectively. Flour stored in paper bags showed less change across these parameters compared to flour in polypropylene bags, which offered better protection against atmospheric oxygen.

Gupta and Singh (2005) found that various biscuit types exhibited increases in acid value and moisture content after interval of two months of storage at room temperature. Biscuits made with quality protein maize showed a slower increase in acid value and moisture content compared to those made with wheat flour.

Sharon and Usha (2006) assessed the fiber content of bread fruit flour before and after storage. The fiber level decreased slightly from 4.3% to 4.2%. Initial concentrations of calcium (82.2 mg/100g), phosphorus (67.2 mg/100g), and iron (5.3 mg/100g) showed minimal reduction, dropping to 77.8 mg/100g, 60.7 mg/100g, and 5.0 mg/100g, respectively, after storage.

Kumar and Barmanray (2007) observed that the moisture content of biscuits increased significantly during storage. After five months, biscuits containing 5-15% mushroom powder lost their crunchiness, while those with 20% mushroom powder maintained their texture for up to four months.

Capriles et al. (2008) explored how snacks with varying levels of saturated and trans fats performed over time. Snacks made with rapeseed oil, which had lower saturated and trans fats, compared favorably to those made with partially hydrogenated vegetable oil after 20 weeks of storage. Sensory evaluations indicated that both types of snacks were equally well-received by consumers.

Chitra et al. (2008) examined the shelf life and quality retention of noodles packed in 200-gauge polypropylene bags. The noodles maintained a 90-day shelf life with consistent color and flavor. However, moisture content increased in both control and treated noodle samples over the storage period. Noodles with added carrot powder showed increased moisture content varying from 6.52% to 7.76% and experienced a loss of carotene between 37% and 93.20%, compared to 32.78% in the control group.

Kanchana et al. (2008) monitored moisture content changes in spirulina biscuits over time. The moisture level increased from 4.0% in the control group to 4.4% in the treatment group. Initial reducing sugar content was 6.02 g/100 g for the control and 6.94 g/100 g for the treatment group, with a gradual reduction in sugar levels during the 90-day storage period. β -carotene content also decreased during storage.

Parimalavalli and Roxana (2010) assessed the storability of biscuits and breads packed in polyethylene bags. They observed no significant changes in biscuits throughout the storage period, while fungal growth appeared in the bread by the fifth day.

Premalatha et al. (2010) analyzed high-fiber noodles packed in various materials over a six months storage period. A gradual increase in moisture content and a notable loss of protein after three months duration was observed, with a slight reduction in fat content across all noodle treatments.

Shaviklo et al. (2010) conducted a six-month storage study on extruded corn-fish snacks. Their findings suggested that a high-protein blend of corn grits, farmed fish mince, and freeze-dried fish protein-maintained stability and freshness for up to five months. Despite some increases in rancidity and off-flavors after five months, the snacks shelf life remained comparable to control products. The study recommended reducing fat levels or using healthier oils like olive oil to enhance the nutritional profile of corn snacks.

Nagi et al. (2012) reported the potential impact of different packaging materials, namely HDPE and laminates, on the quality of wheat flour biscuits made with both whole and refined cereal bran. After a three-month storage period at room temperature, the biscuits maintained high acceptability in both packaging types. Microbiological testing revealed

that bacterial counts remained within safe limits throughout the storage duration. Initially, the total bacterial count was low on nutritional agar. Biscuits made with oat bran had the fewest bacteria, with a count of 11.15×10^2 cfu/g, while those made with rice bran had the highest count at 21.68×10^2 cfu/g. Over time, bacterial counts increased, reaching 19.13×10^2 cfu/g in oat bran biscuits and 23.66×10^2 cfu/g in rice bran biscuits by the end of the storage period. The study concluded that proper packaging could help maintain the microbiological quality of biscuits, as both HDPE and laminates preserved the sensory attributes and microbiological safety of the rice bran biscuits, despite the increase in microbial growth.

Desayi (2012) assessed the quality of biscuits enriched with mushroom powder over fifteen and thirty days of storage by analyzing their microbial content under different treatment conditions. The study observed a notable increase in bacterial counts over the 30-day storage period. Biscuits with 10% mushroom powder and 0.2% vanilla flavor had microbial counts of 0.7×10^2 cfu/g at 15 days and 1.1×10^2 cfu/g at 30 days. In contrast, unfortified control biscuits exhibited higher bacterial counts of 2.0×10^2 cfu/g at 15 days and 2.4×10^2 cfu/g at 30 days. The results suggested that incorporating mushroom powder and vanilla flavor could reduce microbial proliferation during storage, potentially enhancing the biscuits microbiological stability over a 30-day period.

Banusha and Vasantharuba (2014) monitored bacterial counts in wheat flour biscuits (WB) and composite biscuits (CB) over a two-month storage period. After one month, WB biscuits had a bacterial count of 6.8×10^1 cfu/g, while CB biscuits had a count of 2.3×10^2 cfu/g. By the end of the second month, bacterial counts for WB and CB biscuits increased to 9.6×10^2 cfu/g and 3.6×10^2 cfu/g, respectively. Both types of biscuits remained microbiologically safe for consumption throughout the storage period.

Slathia (2014) found that noodles showed the rise in moisture content from 9.54% to 10.48% over three months of storage period. During the same time, there were significant decreases in the contents of crude protein (from 18.69% to 18.49%), crude

fat (from 1.98% to 1.80%), crude fiber (from 2.82% to 2.77%), and ash (from 1.23% to 1.04%).

Sharma (2014) found an increase in the moisture percentage of crackers made with flaxseed flour after three months of storage, alongside a loss in crude protein, crude fat, crude fiber, antioxidant activity, total phenols, and minerals.

Alam et al. (2015) observed the shelf life of rice snacks by adding carrot pomace and chickpeas. They found that when these extruded snacks were stored in vacuum-sealed aluminum laminate bags, they remained nutritionally stable and retained their flavor for up to six months.

Hussain (2016) investigated the nutritional and microbiological aspects of multigrain biscuits over a 90-days period. The study revealed reductions in antioxidant activity, moisture, crude protein, fat, fiber, ash, and mineral content, while microbial counts increased significantly, rising from 3.07% to 4.46% and from 2.46×10^3 to 4.88×10^4 , respectively.

Gautam et al. (2017) evaluated the storage longevity of various handcrafted extruded snacks made from malted composite flours, such as namkeen sev, chakli, seviyan, and kachori. Sealed in HDPE, these snacks showed a gradual increase in moisture content during storage. They maintained low peroxide levels, indicating good oxidative stability, and can be consumed safely for duration of three months. The study highlighted the potential for these snacks to offer a nutritious alternative by incorporating ingredients like pearl millet, chickpeas, malted wheat, and soybean flour.

Choudhary (2018) reported that the microbial count in cookies made with mango peel powder increased significantly over 90 days of storage, rising from 1.38×10^3 to 3.68×10^4 cfu/g.

Kaur et al. (2018) assessed the freshness of extruded corn products made from both conventional and high-protein corn after 6 months of room temperature storage. They found that, despite slight variations in the percentages of moisture and free fatty acid indicating slight oxidation, however the overall quality of the snacks remained stable, maintaining their shelf-stable status.

From the reviewed literature, there appears to be limited focus on developing low-glycemic-index pasta. Goni et al. (2002) explored low-GI pasta formulations using chickpea flour, noting that pasta made with 25% chickpea flour had a lower glycemic index and higher mineral content compared to durum wheat pasta. Sabanis et al. (2006) found that adding chickpea flour to durum wheat lasagna improved its stiffness and color intensity. Petitot et al. (2009) developed a spaghetti recipe using 35% legumes, such as split peas or faba beans, to enhance nutritional value. Baljeet et al. (2019) evaluated extrudates with maize grits and 10% to 30% buckwheat flours, finding the most palatable option to be pasta with 20% buckwheat flour. Additionally, Baljeet et al. (2010) assessed biscuits with 20-30% buckwheat flour, while Bojnanska et al. (2009) and Levent and Bilgicli (2011) found biscuits, cookies, bars, and other products made with 30% chickpea flour to be satisfactory. The use of easily digestible buckwheat and chickpea flours holds promise for producing low-glycemic pasta extrudates.

Based on the critical analysis of lacunae for the available state of art, following objectives have been carried out in the current proposal.

1. Standardization of various ingredients for the development of cold pasta extrudates using chickpea and buckwheat flour.
2. Optimization of process conditions for the development of low glycemic chick pea and buckwheat based cold pasta extrudates with xanthan gum and carboxymethyl cellulose.
3. Storage and packaging evaluations for optimal targeting cold pasta extrudates.

CHAPTER 3

MATERIALS AND METHODS

This chapter focuses on procedural approaches for research design and analytical methodologies for various objectives.

3.1 Raw material

3.1.1 Procurement of raw materials

The raw materials such as buckwheat and chickpea were procured from KVK, Gurez of SKUAST-Kashmir (34.08 °N and 74.79 °E) and KVK Samba of SKUAST-Jammu (32.72 °N and 74.85°E) respectively. All samples were brought to laboratory and packed in airtight polyethylene bags to prevent any external contamination.

3.2 Preparation of buckwheat and chickpea flour

Raw materials and sample preparation

Buckwheat (common variety) and chickpea (*Fagopyrum esculentum*) grains were first washed and then dried in the month of May using sun drying for 5 days with exposure time of 7-8 hours per day to sun. These were then sorted to remove the foreign particles. The dried and cleaned samples were then ground into flour in mill so that they can pass through 200 μ sieve. The flour obtained was kept in an airtight packaging material until further use.

3.3 Preparation of pasta

The pasta was prepared with varied buckwheat and chickpea (G-1581) flours using a cold extruder (Pasta and Noodle Maker, Model 16009 Make, Kent). Trial and error approach has been adopted with six (06) formulations including a control formulation with buckwheat and chickpea varied from 100-50% and 0-50% respectively to optimize and characterize the pasta formulations. On the other hand, water and salt concentration were kept constant at 40% and 1.5%, respectively for all the combinations.

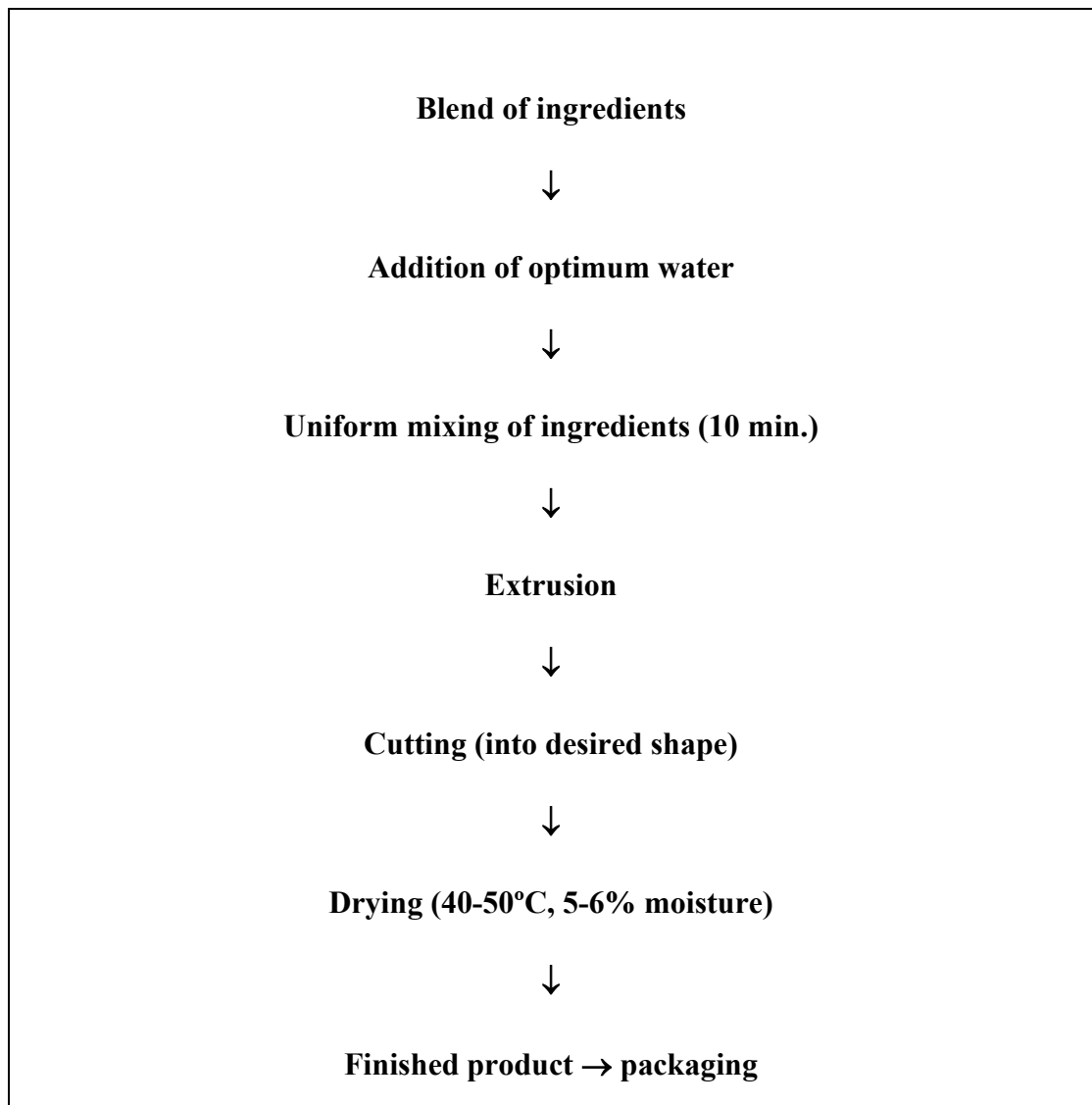


Fig 3.1: Flow sheet for preparation of pasta extrudates

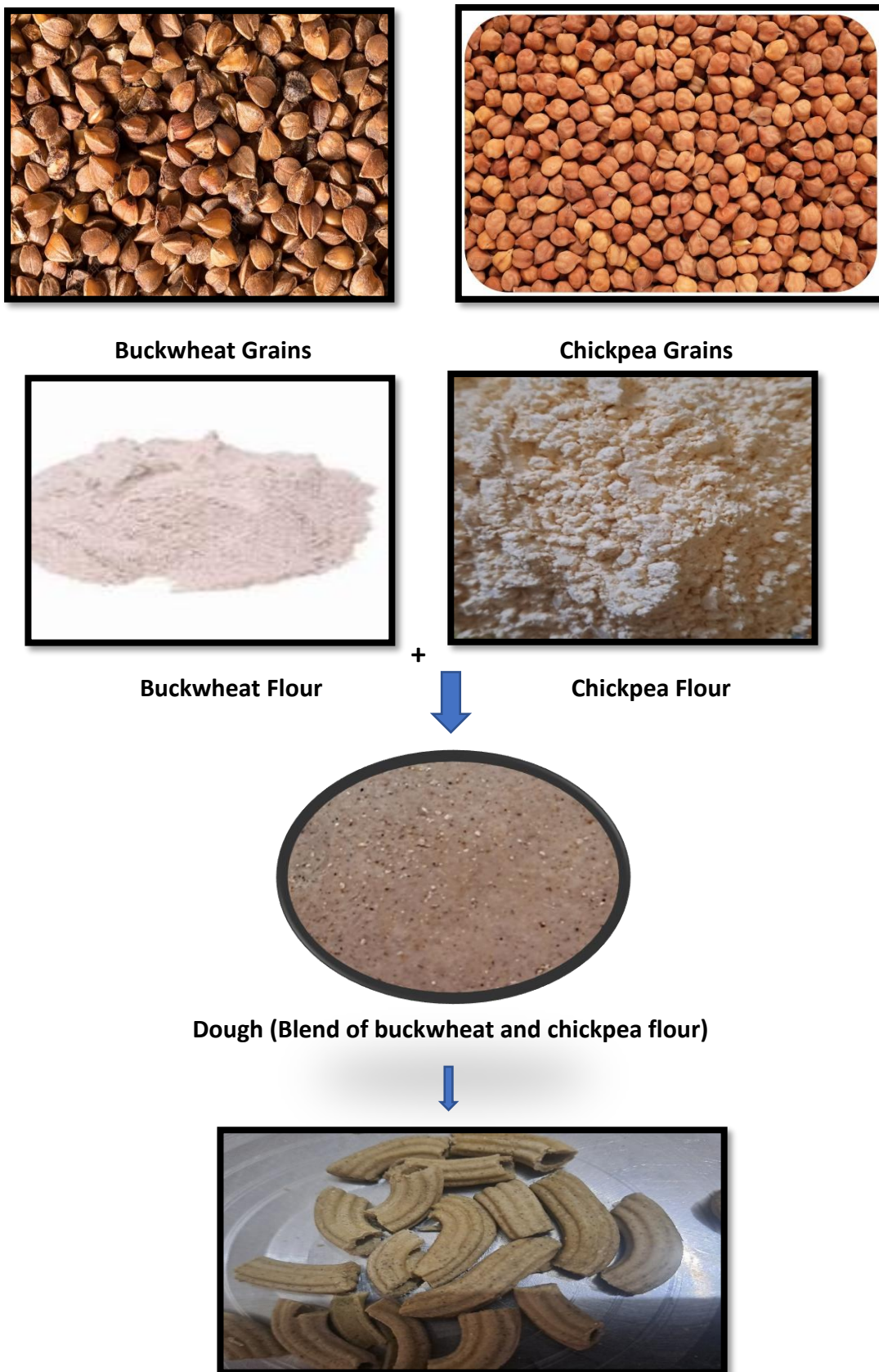


Fig.3.2: Flow sheet representation of prepared pasta

3.4 Standardization of various ingredients for the development of cold pasta extrudates using chickpea and buckwheat flour.

3.4.1. Formulation of different blends for the development of cold pasta extrudates.

Different types of pasta with varied levels of buckwheat (50-100%) and chickpea (0-50%) were prepared using a cold extruder (Pasta and Noodle Maker, Model 16009 Make, Kent). Lukewarm water was added gradually and continuous scrapping was done to avoid surface fouling. It was allowed to mix well and the dough was formed which took 10 mts. automatically in the extruder. After this, the extruder was switched on to prepare pasta with desired shape provided by the die attached to it. The collected pasta was then dried using a tray drier at 40°C until its moisture reached about 5-6%. After this, the extrudates were allowed to cool at room temperature followed by packaging and storage in Ziplock bags for further use (Han et al., 2021).

The abovementioned combinations of samples were evaluated for cooking quality parameters namely cooking time, water uptake ratio, solid gruel loss, volume expansion and swelling index, texture profile analysis, and sensory quality attributes. Further, the formulation was optimized to minimize cooking time and solid gruel loss and maximize volume expansion, water uptake ratio, and swelling index.

Table 3.1. Different treatment combinations for preparation of pasta

Treatments	Chickpea (%)	Buckwheat (%)
T₁	0	100
T₂	10	90
T₃	20	80
T₄	30	70
T₅	40	60
T₆	50	50

*Water and salt were kept constant at 40% and 1.5%, respectively in all the treatment combinations.

Each of the treatment combination above was evaluated for cooking quality parameters viz. minimum cooking time, Solid Gruel Loss, water uptake ratio, volume expansion and swelling index, texture profile analysis and sensory quality attributes. The criteria for standardization were to: (a) minimize cooking time, (b) maximize water uptake ratio, (c) minimize solid gruel loss, (d) maximize volume expansion and (e) maximize swelling index.

3.4.2. Evaluation of cooking quality of pasta

3.4.2.1 Cooking time

Cooking time was determined using procedure mentioned in American Association of Cereal Chemists (AACC, 2000). Cooking time was measured based on disappearance of the opaque center of samples during cooking in water. Briefly, 5 g pasta sample was cooked in a beaker containing 75 ml of distilled water. Pasta extrudates were pressed between two plates after every 30 seconds. The maximum cooking time of pasta extrudates was recorded when the white bubble reaction of cooked pasta disappeared.

3.4.2.2 Water uptake ratio

The water uptake ratio (WUR) was determined as the ratio of the weight of cooked pasta to the weight of pasta before cooking (AACC, 2000) using the equation as follows:

$$\text{Water uptake ratio (\%)} = \frac{\text{weight of cooked pasta} - \text{weight of raw pasta}}{\text{weight of raw pasta}} \times 100 \quad (1)$$

3.4.2.3 Solid Gruel Loss (%)

The amount of solid substance lost to the cooking water was used to determine the solid gruel loss of cooked pasta extrudates (AACC, 2000). Along with 300 milliliters of boiling water, about 10 grams of pasta extrudates were added. After the cooking was done, the cooking water was poured into an aluminum pan followed by baking at 105 °C (degree Celsius) until it was completely evaporated. By applying the following

formula to the weighed residue, we were able to determine the percentage of solid gruel loss.

$$\text{Solid Gruel Loss (\%)} = \frac{\text{Dried residue in cooking water}}{\text{weight of pasta before coking}} \times 100 \quad (2)$$

3.4.2.4 Swelling index

Cooked pasta extrudates were tested for their swelling index (SI) using the method given by (Cleary and Brennan, 2006). Before being rinsed with 100 ml of cold water, 10 grams of the sample were cooked in 300 ml of boiling water. Two measurements were taken of the pasta extrudates' diameters—one before cooking and one after—using the following equation:

$$\text{Swelling Index} = \frac{D_2 - D_1}{D_1} \times 100 \quad (3)$$

Where,

S.I = Swelling Index

D_2 = Diameter of pasta extrudates after cooking

D_1 = Diameter of pasta extrudates before cooking

3.4.2.5 Volume Expansion Ratio

The volume expansion ratio was measured using the methodology mentioned in previous literature (Filli et al., 2012). Therefore, volume expansion ration has been determined using the following expression:

$$\text{Expansion ratio} = \frac{D}{d} \quad (4)$$

Where, D and d, refers to the diameter of extrudates and die in mm respectively.

3.4.3 Texture Profile Analysis

The profile testing was conducted using an equipment, texture analyzer (TA-XT2, Stable Micro System Ltd., Surrey, UK) equipped with a 5 kg load cell tool. The

measurements were repeated ten times. Various textural metrics were derived from the force-time curve (Bourne, 2002), such as hardness (g), cohesiveness ($A2/A1$), springiness (cm), gumminess (N), and chewiness (g cm) ($\text{hardness} \times \text{cohesiveness} \times \text{springiness}$). With the P-36-cylinder probe, you may set the pre-test speed to 2 mm/s, the strain test speed to 75%, the auto trigger type to 10 g, and the data acquisition speed to 200 p/s. Two strips of spaghetti were also tested simultaneously. The pasta's hardness was determined using a combination of a Light Knife Blade probe and the AACC (16-50) Standard method. Data was captured at 400 points per second, with a test speed of 0.17 mm/s and a post-test speed of 10 mm/s. The distance covered was 4.5 mm, and the button type was trigger. By default, these were the settings for this method. According to Bagdi et al. (2014), five spaghetti strips were placed under the blade in a perpendicular fashion.

3.4.4 Color measurement:

3.4.4.1. Hunter color values (L^* a^* b^*)

Hunter Lab color analyzer (Hunter Lab Color Flex, Reston, VA, USA) was used to measure the color characteristics of the extrudates from the pasta. Lightness, denoted by L^* and ranging from zero to one hundred, was used to represent the color reading values in terms of the Hunter values for a^* and b^* . When calibrating the apparatus, white and black ceramic tiles, which are standard, were utilized. Colors green and reddish-purple are represented by positive and negative values of a^* , respectively. If b^* is positive, then the color is yellow, and if it is negative, then the color is blue.

3.4.5 Sensory evaluation

A sample of cooked pasta extrudates prepared using various formulations was evaluated with an experienced and pre-trained panel of 10 judges of age group between 21-55 years including faculty members, research scholars and students. The panel has been asked to evaluate the pasta extrudates for the parameters such as appearance, color, texture, taste, and overall acceptability). For such case, 9-point hedonic scale with extreme values i.e., 1 and 9 indicating dislike and like extremely respectively.

3.5. Optimization of the process conditions for development of low glycemic index (GI) chickpea and buckwheat-based pasta extrudates with xanthan gum and carboxymethyl cellulose.

3.5.1 Process optimization for xanthan gum incorporated extrudates

3.5.1.1 Experimental design

The impact of buckwheat (A), chickpea (B), and xanthan gum (C) on dependent variables such as glycemic index, glycemic load, resistant starch, solid gruel loss, and cooking time was investigated using Box Behnken Design (BBD). Based on the coded-levels of the independent variables and the experimental ranges, Table 3.2 provides the relevant information.

Table 3.2. Coded and decoded-levels of independent variables

Process variables	Code	Variable level codes		
		-1	0	1
Buckwheat	A	65	75	85
Chickpea	B	15	25	35
Xanthan gum	C	1.5	2.5	3.5

The table 3.2 indicates that the buckwheat levels ranged from 65-85 % with central point as 75. Similarly, chickpea concentration ranged from 15-35% and xanthan gum ranged from 1.5 -3.5 % with central points as 25 and 2.5 respectively.

The experimental data for each response was fitted using second-order polynomial models for dependent variables, which were developed using Stat Ease Inc's statistical software, Design Expert 12.0 (Minneapolis, MN, USA).

$$y_i = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1x_2 + b_5x_2x_3 + b_6x_3x_1 + b_7x_1^2 + b_8x_2^2 + b_9x_3^2 \quad (5)$$

The variables buckwheat, chickpea, and xanthan gum are considered independent variables in this context. The coefficients for the intercept, linear, quadratic, and interaction effects are denoted as b_1 , b_2 , b_3 , and $b_4 \dots b_9$, respectively. Analysis of variance (ANOVA) was used for each response to check for statistical significance of the terms, and multiple regression analysis was used to evaluate the data.

By employing numerical optimization with the response surface of the desirability function, the procedure for preparing extrudates with xanthan gum was optimized. To optimize numerically, we minimized glycemic load, glycemic index, cooking time, solid gruel loss, and maximized resistant starch using the optimal condition criteria.

3.5.2 Process optimization for Carboxymethyl cellulose incorporated extrudates

3.5.2.1. Experimental design

The impacts of 3 independent variables buckwheat (A), chickpea (B), and carboxymethyl cellulose (C) on dependent variables glycemic load, glycemic index, solid gruel loss resistant starch, and cooking time were examined using Box Behnken Design (BBD). Table 3.3 displays the experimental ranges and the corresponding coded-levels of the independent variables.

Table 3.3: Coded and decoded-levels of independent variables

Process variables	Code	Variable level codes		
		-1	0	+1
Buckwheat	A	65	75	85
Chickpea	B	15	25	35

Carboxymethyl	C	1.5	2.5	3.5
Cellulose				

The table indicates that the buckwheat levels ranged from 65-85% with central point as 75. Similarly, chickpea concentration ranged from 15-35% and carboxymethyl cellulose ranged from 1.5 -3.5% with central points as 25 and 2.5 respectively.

Statistical Software Design Expert 12.0 (Stat Ease Inc, Minneapolis, MN, USA) was used to form second order polynomial models for dependent variables to fit the experimental data for each response.

$$y_i = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1x_2 + b_5x_2x_3 + b_6x_3x_1 + b_7x_1^2 + b_8x_2^2 + b_9x_3^2 \quad (6)$$

Here, buckwheat, chickpea, and carboxymethyl cellulose are the independent variables, and the coefficients for the intercept, linear, quadratic, and interaction effects are b_1 , b_2 , b_3 , and $b_4 \dots b_9$, respectively. Analysis of variance (ANOVA) was used for each response to check for statistical significance of the terms, and multiple regression analysis was used to analyze the data.

By employing numerical optimization with the response surface of the desirability function, the procedure for preparing extrudates with carboxymethyl cellulose was optimized. To optimize numerically, it is important to search for conditions that would reduce glycemic load and index while simultaneously increasing resistant starch and decreasing cooking time solid gruel loss.

3.5.2.2 Determination of product response

3.5.2.2.1 Glycemic index

Following the methods described by Goni et al. (2003), the in vitro glycemic index (GI) of the sample was determined. Except for white bread, all samples were gelatinized by immersing them in 5 cc of tap water and heating them in sealed tubes at 80°C for 30 mts. After 10 milliliters of HCl-KCl buffer (pH 1.5) was added, it was homogenized for 2 mts. The next step was to combine each sample with 0.2 milliliters of pepsin in 10 milliliters of HCl-KCl buffer (pH 1.5). A 60-minute incubation period was subsequently elapsed in a shaking water bath set at 40°C. After the samples were

incubated, 25 ml of trismaleate buffer (pH 6.9) was added to each. After being mixed with 5 ml of trismaleate buffer with 2.6 IU of α -amylase (Sigma Aldrich) produced from swine pancreas, each sample was incubated in a shaking water bath at 37°C. The purpose of this procedure was to produce maltodextrins. Parts of 0.1 ml were extracted from each flask at 0, 30, 60, 90, 120, 150, and 180 mts. in order to stop the α -amylase from doing its job. These parts were subsequently boiled in water for 5 mts. Amyloglucosidase (Sigma Aldrich) and 0.4 M sodium-acetate buffer (pH 4.75) were added to 1 ml of maltodextrins per part, and then incubated at 60°C for 45 mts. to hydrolyze them into glucose. All samples had their glucose levels measured using an enzyme kit made by Megazyme.

At 0,30,60,90,120,150, and 180 mts., the starch digestion rate was measured as the proportion of total starch hydrolyzed. Using Eqs. (7)-(9), we were able to determine the starch hydrolysis kinetics, AUC, HI, and GI, in that order;

$$C = C_0(1 - e^{-kt}) \quad (7)$$

$$AUC = C_{\infty} (t_f - t_0) - (C_{\infty}/k) (1 - e^{-K(t_f - t_0)}) \quad (8)$$

$$HI = \left(\frac{AUC_{\text{sample}}}{AUC_{\text{white bread}}} \right) \times 100 \quad (9)$$

$$GI = 39.71 \pm .549 \text{ HI}$$

The variables to be considered in determining the hydrolysis index (HI) are the following: the hydrolyzed starch percentage at time t, the hydrolyzed starch percentage after 180 mts., the kinetic constant (k) in units of min^{-1} , the time (t), the final time (t_f) in mts., the initial time (t_0) in mts., and the treated sample's area under the curve (AUC) divided by the white bread's corresponding area, expressed as a percentage.

3.5.2.2.2. Glycemic load

The glycemic load (GL) of the sample was determined (Ijarotimi et al., 2021) using the following equation:

$$\text{Glycemic Load (GL)} = \frac{\text{Available carbohydrates} \times \text{Glycemic index}}{100} \quad (10)$$

where, available carbohydrate is determined by subtracting dietary fiber from total carbohydrates.

3.5.2.2.3 Resistant Starch (RS)

Goni et al. (1997) provided the methodology that was used to determine resistant starch. Initially, pepsin (Merck 7190, Darmstadt, Germany; 4 °C, 1 h, p^H 1.5) and α -amylase (Sigma A-3176, Madrid, Spain; 37 °C, 16h, pH 6.9) were used to remove digestible starch and protein, respectively. After centrifugation, the leftovers were dissolved by dispersing them in 2 M KOH. Amyloglucosidase was subsequently added to the mixture. Spectrophotometric measurements of glucose were taken with the GOPOD reagent (676543, Roche Diagnostics, Barcelona, Spain). The RS formula is as follows:

$$\text{Resistant Starch} = \text{mg glucose} \times 0.9$$

3.5.2.2.4 Cooking time (CT): As explained under sub section 3.4.2.1

3.5.2.2.5 Solid Gruel Loss (SGL): As explained under sub section 3.4.2.3

3.6 Physicochemical characteristics of the developed/optimized products by using buckwheat, chickpea and xanthan gum/ carboxymethyl cellulose.

The developed and optimized products shall be analyzed for the below mentioned physicochemical characteristics.

3.6.1 Proximate composition

3.6.1.1 Moisture Content

With the help of Citizen MB 50 C electronic moisture analyzer, the moisture content was analyzed 2 g of material was put into the sample holder made up of aluminum to deposit it before inserting it into the analyzer and heated upto to 105 °C. According to Jalgaonkar et al. (2017), the percentage of moisture content was used to automatically determine evaporative moisture losses.

3.6.1.2 Crude Protein

The 2.0 g sample was subjected to a 2-hour digestion process in a 500 ml Kjeldahl digestion flask containing 2 g of catalyst (K₂ SO₄, CuSO₄, and SeO₂) and 25 ml of concentrated sulphuric acid (98%) until it was carbon free. Transferring the samples of the digestion flask into the volumetric flask having capacity of 100 ml followed by

adding 10 ml of double distilled water when the contents cooled and attained room temperature. 10 ml of 4% boric acid solution and 2-3 drops of mixed methyl red and bromocresol green indicator were put into the flask and ammonia was extracted after a determined aliquot was collected through a condenser from distilled 40% NaOH (11.25 N). The solution was titrated against 0.1 N standard sulphuric acid. According to Jamal et al. (2020), distillation and blank (reagent) digestion were done at the same time. To determine the crude protein content, we used equation (11).

$$\text{Nitrogen (\%)} = \frac{\text{Titre value}}{\text{Aliquot taken (g)} \times \text{weight of sample (g)}} \times 100 \quad (11)$$

$$\text{Percent Protein} = \text{Percent Nitrogen} \times 6.25$$

3.6.1.3 Crude Fat

Evaluation of crude fat was carried out using the Soxhlet extraction method. The lipid component of the sample was readily removed by refluxing it for six hours in petroleum ether, an organic solvent, at 120 °C (Akoh, 2017). The fat content was measured by adding the weight of the beaker to the ether extract in the pre-weighed beakers, which was entirely evaporated. The formula for this was as follows:

$$\text{Crude fat (\%)} = \frac{\text{Amount of evaporated residue (g)}}{\text{weight of sample (g)}} \times 100 \quad (12)$$

3.6.1.4 Ash content

In order to find the ash content, the AOAC standard procedure (2012) was utilized. About 5 grams of the material was dried in a silica crucible that had been previously weighed. Smoking off fat required preparatory ashing, which was accomplished by gradually heating over flame to avoid burning. Once the smoke stopped evaporating off the specimen, it was burned for 8 hours at 600 °C ±10 °C in a muffle furnace. We weighed the crucibles after removing them from the oven and letting them cool in desiccators. To find the amount of ash, we used the following formula:

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{weight of sample (g)}} \times 100 \quad (13)$$

3.6.1.5. Determination of Crude fibre

In a 500 ml beaker, a fat-free sample weighing 2 grams was added to 200 ml of a 1.25% H₂SO₄ solution. The contents of the beaker were then heated on an adjustable hot plate for 30 mts. on a digestion apparatus. The sample present in the beaker were filtered using Whatman filter paper no. 4 when boiling took place. Then, the rinsing was done by using filter paper with hot distilled water to remove any residual acid. After that, combine the filter paper and residue with 200 cc of a 1.25% NaOH solution in a beaker. During the process, the beverage underwent three rounds of rinsing with hot water and alcohol to eliminate any remaining alkali after 30 mts. of digestion. After re-weighing the filter paper residue, it was placed on previously measured silica crucibles and dried using hot air oven at 100°C. The muffle furnace was used to heat the crucibles for 30 mts. at a temperature of 600 ± 15°C. This is how the weight loss after ignition was calculated to reflect the crude fiber in the sample, according to AOAsC (2012):

$$\text{Crude fiber (\%)} = \frac{\text{Loss of weight after ignition (g)}}{\text{weight of sample(g)}} \times 100 \quad (14)$$

3.6.1.6. Total Carbohydrates

The difference approach was used to determine the carbohydrate content (AOAC, 2012). It was analyzed by adding the moisture, fat, protein, fiber and ash percentages, and then deducting the total percentage obtained from 100.

$$\text{Weight of sample (g) Carbohydrate (\%)} = 100 - (\text{moisture \%} + \text{fat \%} + \text{protein\%} + \text{ash\%} + \text{fiber\%}) \quad (15)$$

3.6.2. Textural analysis: As explained under sub section 3.4.3

3.6.3 Color analysis: As explained under sub section 3.4.4

3.6.4. Cooking quality parameters

The cooking quality parameters namely cooking time, solid gruel loss, water uptake ratio, volume expansion and swelling index were evaluated as per the methods described earlier under sub-headings 3.4.2.1 to 3.4.2.5.

3.6.5 Energy value (Kcal/100)

The energy value of the sample is determined by applying the following equation taken from Barros et al. (2010).

$$\text{Energy (Kcal)} = (C \times 4) + (P \times 4) + (F \times 9) + (D \times 2) \quad (16)$$

Where, C = Carbohydrate weight (g)

P = Proteins (g)

F = Fat weight (g)

D = Total dietary fibre weight (g)

3.6.6 Water Activity (a_w)

When microorganisms can proliferate in an environment with enough free or accessible water, this is called water activity. A water activity meter cup was filled three quarters of the way with the sample. Device was adjusted in accordance with the calibration procedure outlined in the user handbook. A steady reading was achieved by keeping the sample in a cup (Jalgaonkar et al., 2017)

3.6.7 Estimation of total sugars (%)

Lam et al. (2021) provided the method for estimating sugars. The sample, which weighed 10 grams, was added to 100 milliliters of water in a 250-millilitre volumetric flask. The mixture was then neutralized with 40 percent sodium hydroxide (NaOH) using phenolphthalein as an indicator and allowed to sit until it became pink. The precipitation of foreign matter was facilitated by 45% lead acetate, and the excess lead acetate was eliminated by 22% potassium oxalate. Total sugars were determined using the filtrate, which was made to 250 ml by preparing the volume and filtering it with Whatman No. 4 filter paper.

3.6.8 Reducing Sugars (%)

Reducing sugars of leadfree solution was measured by titrating it against boiling Fehling solution A and B (5 ml) using methylene blue as an indicator till a brick red color appears at the end point (Lam et al., 2021). The reducing sugars were calculated in percent.

$$\text{Reducing sugars (\%)} = \frac{\text{Factor} \times \text{dilution}}{\text{Aliquot used (ml)} \times \text{weight or vol. of sample (g or ml)}} \times 100 \quad (17)$$

3.6.9 Minerals (Ca, Fe, Mg, Zn)

The sample was first prepared by using mineral solutions of samples to be analyzed by following wet ashing methods as suggested by Jan and Mogra (2006) Then the prepared sample was subjected to digestion with multiple acids to make clear white precipitates

which were then dissolved in water to attain a definite volume. An aliquot from this was used for determination of selected minerals.

3.6.10 Starch (%)

Past work by Pautong et al. (2022) details the steps used to calculate TS. In order to hydrolyze the starch, 50 mg of samples were dispersed in 2 M KOH. Then, the samples were treated with amyloglucosidase at 60 C for 45 mts. at a pH of 4.75. With the use of the Peridochrom Glucose GOPOD (676 543, Roche Diagnostics, S.L. Barcelona, Spain), starch was determined to be glucose. After measuring the glucose content, the starch was measured by multiplying the glucose by 0.9.

3.6.11 Glycemic Index: As explained under subheading 3.5.1.2.1

3.6.12 Glycemic load: By using the same procedure as described under subheading 3.5.1.2.2.

3.6.13 Resistant starch: As mentioned previously under subheading 3.5.2.2.3.

3.6.14 Sensory Evaluation: By following the same procedure as explained previously under subheading 3.4.3.

3.7 Statistical analysis

In order to optimize the process variables numerically, Statistical Software Design-Expert 12, developed by Stat-Ease Inc. of Minneapolis, MN, USA, was used. For every one of the response functions, the ANOVA tables were made. To evaluate the impact of buckwheat, chickpea, and xanthan gum, the experimental design's response data was analyzed using regression. A minimum glycemic index, glycemic load, solid gruel loss, cooking time, and resistant starch were the numerical optimization criteria. The generated pastas' physicochemical qualities were compared using Student's t-test, and all measurements were made in triplicate. A p value less than 0.05 was used to define the statistical difference.

3.8 Storage and packaging evaluations for optimal targeting cold pasta extrudates.

3.8.1 Water activity: As explained under subheading 3.6.6

3.8.2 Moisture content: As explained under subheading 3.6.1.1

3.8.3 Free fatty acids

To determine the free fatty acids (FFA) in pasta extrudates while they were stored, the standard AOAC (2005) protocol was performed. 5 g sample taken followed by addition

of 50 ml benzene, the FFA was extracted by letting it sit for 30 mts. 5 ml of extract, 5 ml of benzene, 10 ml of alcohol, and phenolphthalein proportions were added and also treated with 0.02N KOH in a flask for measurement. The color was allowed to fade thereafter. The formula used to find the FFA value is as:

$$\text{FFA (as oleic acid)} = \frac{282 \times 0.02 \text{ N KOH} \times \text{ml of alkali} \times \text{dieteray fibre}}{1000 \times \text{weight of sample (g)}} \times 100 \quad (18)$$

3.8.4 Total plate count

The approach described by Pelczer and Chan (1993) was used to calculate the total number of plates. Aseptically, one gram (1 g) of sample in nine milliliters (9 ml) of sterile water was put in a test tube followed by thorough mixing. 1 ml was transferred from the mixing tube to a test tube that contained 9 ml of sterile water. This process was carried out up to the sixth dilution, which was 10^{-6} for thorough mixing. By using the spread plating approach, 0.1 ml of a diluted sample (10^{-6}) was added to nutrient agar (NA), and then the mixture was incubated at 37°C for 24 hours. After counting the colonies, the dilution factor was used to multiply them. Log colony forming unit (log cfu) of sample was the unit of expression for the total plate count data.

$$\text{Microbial load} = N \times \frac{1}{V} \times D \quad (19)$$

Where,

N= No. of the colonies counted

V= Volume of the inoculums

D= Dilution factor

3.8.5 Sensory evaluation (As explained under subheading 3.4.5)

CHAPTER 4

RESULTS AND DISCUSSION

This chapter describes the results and discussion

The Proximate composition of buckwheat and chickpea flour was determined by following AOAC 2000 Approved Methods of Analysis. The moisture content of buckwheat flour and chickpea flour was found to be 9.02 and 8.89 % respectively. The crude protein, crude fat, carbohydrates, ash, crude fibre and calorific value of buckwheat flour were found to be 10.52, 2.61, 63.09, 1.31, 5.30 and 323 whereas the crude protein, crude fat, carbohydrates, ash, crude fibre and calorific value of chickpea flour were observed as 21.52, 4.02, 60.15, 4.62, 4.01 and 361.45 respectively.

The proximate composition of buckwheat and chickpea flour per 100 gm is as under:

Parameter	Buckwheat flour	Chickpea flour
Moisture Content (%)	9.02±0.05	8.89±0.05
Crude Protein (%)	10.52±0.03	21.52±0.01
Crude Fat(%)	2.61±0.05	4.02±0.03
Carbohydrates	63.09±0.09	60.15±0.05
Ash (%)	1.31±0.03	4.62±0.01
Crude Fiber	5.20±0.01	4.01±0.13
Calorific Value (Kcal/100g)	323±0.07	361.45±1.89

4.1 To standardize the various ingredients for the development of cold pasta extrudates using chickpea and buckwheat flour

4.1.1. Cooking Quality characterization

4.1.1.1 Cooking time: Table 4.1 describes cooking time variations for various pasta formulations. The cooking time ranged from 3.19- 4.28 mts. for the variation of buckwheat and chickpea flour from 50-100 % and 0-50 % respectively. The values of cooking time in mts. showed marginal differences for the preparations with different

concentrations of buckwheat and chickpea flour. The minimum cooking time value was observed for T₆ (buckwheat: chickpea, 50:50) whereas the maximum cooking time value was found in case of control formulation (100:0 buckwheat: chickpea). Similar observations were found for chickpea flour and protein isolate enriched pasta (El-Sohaimy et al., 2020). The higher cooking time observed for formulation T₆ is attributed to the increased chickpea flour content, which enhances the protein content in the pasta formulation. This aligns with findings from Padalino et al., 2014 which indicate that higher protein content generally results in longer cooking times due to altered water diffusivity and protein-starch interactions within the pasta matrix.

Table 4.1: Cooking quality characteristics of buckwheat and chickpea flour based cold extrudates

Sample	Chickpea (%)	Buckwheat (%)	Cooking time (min)
T ₁	0	100	4.28 ± 0.018 ^f
T ₂	10	90	4.10 ± 0.015 ^e
T ₃	20	80	4.0 ± 0.03 ^d
T ₄	30	70	3.85 ± 0.01 ^c
T ₅	40	60	3.71 ± 0.03 ^b
T ₆	50	50	3.19 ± 0.09 ^a
C.D (p≤0.05)			0.04

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.1.2. Water Uptake Ratio

The water uptake ratio of a cooked product refers to the amount of water absorbed by the product during the cooking process, typically is the ratio or percentage of its actual dry weight. Table 4.2 describes the variation of water uptake ratio (WUR) for various pasta formulations. The values of water uptake ratio showed increasing trend from 2.00 to 2.80. This enhancement in values could be due to the highest protein content present in chickpea flour as it is rich in proteins. Soyabean incorporated noodles (Bhise et al., 2014) showed the similar results. Higher protein content in pasta can indeed influence water diffusivity, potentially affecting various aspects of pasta quality and cooking

characteristics. Understanding these relationships helps in optimizing pasta formulations to achieve desired texture, cooking properties, and overall consumer satisfaction.

According to Sudhadevi et al. (2014), pasta products that absorb more water during cooking are generally perceived as higher quality due to improved texture, cooking uniformity, and overall palatability. This finding underscores the importance of water uptake ratio as a key parameter in evaluating and optimizing pasta product formulations. The values of water uptake ratio in terms of minimum and maximum were 2.00 and 4.23 for T₁ (control) and T₅ (buckwheat: chickpea 60:40) formulations respectively.

Table 4.2: Water uptake ratio of buckwheat and chickpea flour based cold extrudates

Sample	Chickpea (%)	Buckwheat (%)	Water Uptake Ratio
T ₁	0	100	2.00 ± 0.015 ^a
T ₂	10	90	2.80±0.057 ^b
T ₃	20	80	3.23±0.092 ^c
T ₄	30	70	4.03±0.04 ^d
T ₅	40	60	4.23±0.14 ^e
T ₆	50	50	4.21±0.10 ^e
C.D (p≤0.05)			0.01

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.1.3. Solid Gruel Loss

Solid gruel loss measures the total amount of solids lost in water during the cooking of pasta product. Good quality pasta must have clear water after cooking (Sharma et al., 2018). The values observed in Table 4.3 indicate that control formulations (with higher buckwheat content and no chickpea flour) tend to have higher solid gruel loss. Increasing chickpea flour content and decreasing buckwheat flour content both contribute to reducing solid gruel loss, likely due to the improved binding properties of chickpea flour. These findings are valuable for optimizing formulations to enhance the retention of solids in gruels, which can impact product texture, nutritional value, and consumer acceptability.

The variable possessed a reducing trend with the decrease of buckwheat flour concentration from 80-70% whereas the corresponding reduction of the variable was 8.55-7.38%. This is within the recommended value ($\leq 9\%$) of solid gruel loss (AACC, 2000). The minimum and maximum values of Solid Gruel Loss were 3.73 and 8.55 % and the corresponding formulations referred to T₁ and T₆ respectively. Also, Loubes et al. (2016) reported that decreased values of solid gruel loss reflect the improved quality of cooked pasta which should always exist within 9%. The formation of a physical network due to higher protein content from chickpea flour plays a crucial role in reducing solid loss during the preparation of gruel-like mixtures. This is attributed to the network's ability to control cooking and swelling, thereby improving the overall quality and yield of the final food product (Sharma et al., 2018). Similarly, valid reason for decrease in solid gruel loss is also briefed by Padalino (2015) and also by Suo et al. (2022) with similar justification that the losses decreased with the increase in concentration of chickpea within the range of 0-75% and a good quality pasta should have solid gruel loss less than 12% for better acceptability. The explanation fits well with our results of decreasing the solid gruel loss with an increase in chickpea flour levels.

Table 4.3: Solid Gruel Loss of buckwheat and chickpea flour based cold extrudates

Sample	Chickpea (%)	Buckwheat (%)	Solid Gruel Loss (%)
T ₁	0	100	8.55±0.15 ^c
T ₂	10	90	7.38±0.19 ^d
T ₃	20	80	5.98±0.16 ^c
T ₄	30	70	5.20±0.21 ^b
T ₅	40	60	3.74±0.09 ^a
T ₆	50	50	3.73±0.08 ^a
C.D			0.09
(p<0.05)			

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.1.4. Volume Expansion

Table 4.4 shows the variation of volume expansion for different formulations of pasta product with varied concentrations of buckwheat and chickpea flours. The variable increased with the incorporation of chickpea flour concentration in the formulation. The variation in volume expansion of the pasta formulation i.e., 0.90-1.11% for T₁ and T₅ respectively with changes in chickpea and buckwheat flours ranged from 0-50% and 100-50% and highlights the impact of these ingredients on the physical characteristics of the cooked pasta, particularly in terms of volume increase during cooking, whereas the value enhanced with reduction of buckwheat flour in the pasta formulation. Similar results were also reported for plant protein-incorporated pasta (Kaur et al., 2013). The enhancement of volume expansion with chickpea concentration is due to higher protein content with higher hydration capacity resulting in expansion of the sample during cooking (Kaur et al., 2012).

Table 4.4 Volume Expansion of buckwheat and chickpea flour based cold extrudates

Sample	Chickpea (%)	Buckwheat (%)	Volume Expansion
T ₁	0	100	0.90±0.05 ^a
T ₂	10	90	0.96±0.03 ^b
T ₃	20	80	1.06±0.06 ^c
T ₄	30	70	1.07±0.07 ^c
T ₅	40	60	1.11±0.01 ^c
T ₆	50	50	1.06±0.05 ^c
C.D (p≤0.05)			0.03

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.1.5 Swelling Index

The swelling index of pasta is critical in terms of its cooking behaviour and overall quality. It reflects the gelatinization of starch and hydration of proteins, which are fundamental processes determining the texture, uniformity, and palatability of the cooked pasta product. Therefore, optimizing the swelling index is essential in pasta formulation to achieve desired cooking qualities and consumer satisfaction. Table 4.5 showed the increasing trend of swelling index with increase and decrease of chickpea and buckwheat flours. The trend was $T_1 < T_2 < T_3 < T_4 < T_5 < T_6$. The minimum and maximum values obtained were 18.48 and 22.67 respectively. Corresponding formulations refers to T₁ and T₅ respectively. Similar relationship between swelling index with chickpea flour level was reported for chickpea flour and protein isolate incorporated pasta (El-Sohaimy et al., 2020). This is attributed to enhanced water absorption capacity of chickpea flour (Sorzeet al., 2023; El-Sohaimy et al., 2020)

Table 4.5: Swelling Index of buckwheat and chickpea flour based cold extrudates

Sample	Chickpea (%)	Buckwheat (%)	Swelling Index
T ₁	0	100	18.48±0.13 ^a
T ₂	10	90	20.16±0.04 ^b
T ₃	20	80	21.60±0.25 ^c
T ₄	30	70	22.54±0.06 ^d
T ₅	40	60	22.67±0.07 ^e
T ₆	50	50	22.70±0.22 ^e
C.D (p≤0.05)			0.15

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.2 Texture profile analysis

The significant improvement in TPA parameters (hardness, adhesiveness, springiness, chewiness) with increased chickpea flour content in the pasta formulation indicates enhanced texture quality. This highlights the role of chickpea flour, likely due to its protein content and other functional properties, in optimizing pasta texture for better consumer satisfaction. All texture profile analysis parameters enhanced significantly with increase in chickpea flour in the pasta formulation. Optimizing pasta formulations by incorporating ingredients like chickpea flour, which enhance the gluten network, allows for the production of pasta with desirable texture characteristics. This is critical for meeting consumer preferences and ensuring product quality consistency. Among various parameters, hardness enhanced from 6.22 to 14.56 with corresponding lowest and highest values referred to T₁ and T₆ formulations respectively. Also, similar trend was observed for buckwheat based unroasted extrudates (Singh et al., 2019). Similarly, adhesiveness varied from 0.71 to 0.79 mm for a variation of chickpea from 0-50%. Corresponding highest 0.79 and lowest 0.71 values were achieved for T₆ and T₁ respectively. On the other hand, variation of springiness and chewiness were 0.84-10.40 and 14.60 -17.44 respectively for chickpea and buckwheat varied from 0-50% and

100-50% respectively. Incorporating enhanced chickpea flour in pasta formulations improves the bonding of pasta constituents, providing a stable structure and desirable texture during cooking. This reveals the importance of ingredient selection and formulation in achieving high-quality pasta products. The minimum 0.84 and maximum 10.40 values of springiness have been obtained for T₁ and T₆ respectively. On the other hand, the corresponding formulations were T₁ and T₆ for chewiness. Such increasing trends with enhancement of chickpea concentration can be related higher cooking loss of the pasta sample (Silva et al., 2015).

Table 4.6: Texture profile analysis of buckwheat and chickpea flour based cold extrudates

Sample	Hardness (N)	Adhesiveness (mm)	Springiness (mm)	Chewiness
T ₁	6.22±0.09 ^a	0.71±0.04 ^a	0.84±0.10 ^a	14.60±0.19 ^a
T ₂	7.21±0.18 ^b	0.72±0.03 ^a	0.87±0.08 ^a	15.06±0.20 ^b
T ₃	7.48±0.24 ^c	0.73±0.03 ^a	0.95±0.09 ^b	15.85±0.04 ^c
T ₄	9.38±0.22 ^d	0.75±0.03 ^b	0.98±0.03 ^b	15.95±0.16 ^d
T ₅	12.18±0.10 ^c	0.78±0.05 ^c	1.01±0.05 ^c	16.15±0.13 ^c
T ₆	14.56±0.13 ^f	0.79±0.06 ^c	1.04±0.01 ^c	17.44±0.22 ^f
C. D. (p≤0.05)	0.54	N/A	N/A	0.54

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.1.3 Color profile

Table 4.7 depicts the color values in terms of lightness (L^*), redness (a^*), and yellowness (b^*) obtained for various pasta formulations. L^* values reduced with

enhancement of chickpea flour. The value varied from 70.06-64.41 for T₁ and T₆. The reduction of the variable is in agreement with legume incorporated pasta products (Lorentz et al., 1993; Hardi, 2003; Zhao et al., 2005; Wood, 2009 and Pelitol et al., 2010). Such reduction is due to higher ash content of legume flour present in the pasta products (Oliver et al.,1993).

Further, the results indicated a significant enhancement of a* value (5.13-7.28) with chickpea flour for pasta formulation. Pasta (T₅) with buckwheat: chickpea ratio of 50:50 was found to possess highest value of a*. Similar results have been reported for faba bean flour incorporated pasta wherein a significant increase in redness (a*) value was observed (Pelitol et al., 2010). On the other hand, b* value reduced from 35.20-30.35 for chickpea and buckwheat flours varied from 0-50% and 100-50% respectively. Control pasta was found to be more yellow than T₅ (buckwheat: 60% and chickpea: 40%). The results corroborate well with findings reported for legume flour incorporated pasta product (Lorentz et al., 1993). Reduction of b* value is attributed to the leaching out of color pigments such as carotene and xanthophyll during cooking (Wood, 2009)

Table 4.7 Color profile of buckwheat and chickpea flour based cold extrudates.

Sample	L*	a*	b*
T ₁	70.060±0.12 ^f	5.133±0.11 ^a	35.203±0.18 ^d
T ₂	68.230±0.17 ^e	5.620±0.07 ^b	34.937±0.30 ^d
T ₃	64.110±0.26 ^b	6.253±0.20 ^c	34.850±0.08 ^d
T ₄	64.967±0.32 ^d	6.940±0.04 ^d	33.633±0.07 ^c
T ₅	63.320±0.23 ^a	7.283±0.20 ^c	31.270±0.95 ^b
T ₆	64.413±0.28 ^c	7.280±0.18 ^c	30.353±0.03 ^a
C. D. (p≤0.05)	0.538	0.469	1.305

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly (p ≤ 0.05).

4.1.4 Sensory Evaluation

Table 4.8 summarizes the variation of overall acceptability for various pasta formulations with varied buckwheat and chickpea flours. Overall acceptability value enhanced significantly ($p < 0.05$) from 3.10-7.86 for T₁-T₅ followed a marginal reduction of value from 7.86 to 6.49 for T₅-T₆. The maximum overall acceptability (7.86) has been achieved for T₅ with buckwheat to chickpea ratio of 60:40. This is comparable with optimum foxtail millet extruded snacks with 70 % millet and 30% pulse flours (Deshpande and Poshadri, 2011)

Table 4.8 Sensory evaluation of buckwheat and chickpea flour based cold extrudates

Sample	Overall acceptability
T ₁	3.10 ± 0.12 ^a
T ₂	2.84 ± 1.27 ^a
T ₃	4.64 ± 0.44 ^b
T ₄	5.46 ± 0.09 ^c
T ₅	7.86 ± 0.11 ^e
T ₆	6.49 ± 0.21 ^d
C.D (P ≤ 0.05)	1.70

Data are expressed as average of triplicate with standard deviation and superscripts represents data differing significantly ($p \leq 0.05$).

4.2 To optimize the conditions for development of low glycemic cold extrudates as per the experimental plan

4.2.1 Xanthan gum incorporated extrudates

4.2.1.1 Experimental datasheet

The experimental data obtained at different combinations of buckwheat, chickpea and xanthan gum using BBD design of RSM is presented in Table 4.9. The response values were represented as the mean of triplicates.

Table 4.9 shows the experimental data obtained at various combinations of buckwheat, chickpea and xanthan gum using BBD design of RSM

Std	Run	Buckwheat (A) %	Chickpea (B) %	Xanthan gum (C) %	Glycemic Index (G.I)	Glycemic Load (GL)	Resistant Starch (RS) %	Solid Gruel Loss (SGL) %	Cooking Time (CT) min.
1	17	65	15	2.5	33.85	8.98	5.25	5.06	2.87
2	3	85	15	2.5	30.76	5.76	7.93	4.88	3.02
3	1	65	35	2.5	33.31	8.11	5.37	3.05	4.42
4	13	85	35	2.5	29.74	4.74	8.94	4.66	3.45
5	8	65	25	1.5	32.98	7.98	5.73	4.03	4.13
6	5	85	25	1.5	29.47	4.47	8.68	4.58	3.54
7	9	65	25	3.5	32.71	7.44	5.85	3.25	4.14
8	10	85	25	3.5	29.56	4.1	9.09	4.17	3.98
9	7	75	15	1.5	32.19	7.33	6.84	4.37	3.21
10	15	75	35	1.5	31.06	6.06	6.67	3.67	4.62
11	16	75	15	3.5	31.84	6.67	7.14	4.65	3.63
12	2	75	35	3.5	31.38	5.99	7.44	2.92	4.53
13	11	75	25	2.5	31.76	6.67	7.42	4.75	4.38
14	14	75	25	2.5	31.75	6.75	7.32	4.28	4.29
15	6	75	25	2.5	31.79	6.63	7.32	4.36	4.22
16	4	75	25	2.5	31.75	6.71	7.85	4.4	4.02
17	12	75	25	2.5	31.74	6.9	7.32	4.86	4.07

4.2.1.2. Effect of process parameters (buckwheat, chickpea and xanthan gum) on the responses.

4.2.1.2.1 Effect of buckwheat on glycemic index, glycemic load, resistant starch, solid gruel loss and cooking time.

4.2.1.2.1.1 Glycemic Index

As depicted from the table 4.9 buckwheat possessed negative impact on the glycemic index of the sample. At constant chickpea (15%) and xanthan gum (2.5%) glycemic index reduced from 33.85 to 30.76 with buckwheat variation from 65-85 %. Glycemic index showed reducing trend from 33.31 to 29.74 with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. It also showed negative effect with buckwheat variation of 65-85% from 32.98 to 29.47 at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. Similarly, the values of G.I were found to be reduced from 32.71 to 29.56 with buckwheat variation of 65-85% at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

4.2.12.1.2 Glycemic Load

Buckwheat possessed negative impact on the glycemic load of the sample as depicted in table 4.9. At constant chickpea (15%) and xanthan gum (2.5%) glycemic index reduced from 8.98 to 5.76 with buckwheat variation from 65-85 %. Glycemic load showed reducing trend from 8.11 to 4.74 with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. It also showed negative effect with buckwheat variation of 65-85% from 7.98 to 4.47 at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The values of G.L were found to be reduced from 7.44 to 4.1 with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

4.2.1.2.1.3 Resistant Starch

Table 4.9 clearly showed that buckwheat had a positive impact on the resistant starch of the sample. At constant chickpea (15%) and xanthan gum (2.5%), resistant starch increased from 5.25 to 7.93 with buckwheat variation from 65-85 %. It showed positive trend from 5.37 to 8.94% with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. The values of resistant starch increased with buckwheat variation of 65-85 % from 5.73 to 8.68 % at constant

concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The positive trend of increased resistant starch with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively was found to be from 5.85 to 9.09 %.

4.2.1.2.1.4 Solid Gruel Loss

Buckwheat had a positive effect on the solid gruel loss of the sample as depicted in table 4.9. However, at constant chickpea (15%) and xanthan gum (2.5%), solid gruel loss decreased from 5.06 to 4.88 % with buckwheat variation from 65-85 %. It increased from 3.05 to 4.66 % with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. Solid gruel loss with buckwheat variation of 65-85 % at constant concentrations of chickpea (25%) and xanthan gum (1.5%) was found to be increased to small extent from 4.03 to 4.58 %. However, the values of solid gruel loss were found to increase further with buckwheat variation of 65-85% from 3.25 to 4.17 % at constant concentrations of chickpea (25%) and xanthan gum (3.5%) respectively.

4.2.1.2.1.5 Cooking Time

As depicted from the table 4.9, buckwheat possessed positive impact on the cooking time of the sample. At constant chickpea (15%) and xanthan gum (2.5%), cooking time increased from 2.87 to 3.02 mts. with buckwheat variation from 65-85 %. However, with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) cooking time showed decreasing trend to small extent from 4.42 to 3.45 mts. respectively. It also showed negative effect with buckwheat variation of 65-85% from 4.13 to 3.54 mts. at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The values of cooking time were found to be decreased from 4.14 to 3.98 mts. with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

4.2.1.2.2 Effect of chickpea on Glycemic index, Glycemic load, resistant starch, Solid gruel loss and cooking time.

4.2.1.2.2.1 Glycemic Index

As depicted from the table 4.9, chickpea possessed negative impact on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and xanthan gum

(2.5%) glycemic index reduced from 33.85 to 33.31 with chickpea variation from 15-35 %. Glycemic index showed reducing trend from 30.76 to 29.74 with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. It gets reduced from 32.19 to 31.06 with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from 31.84 to 31.38 at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively. This is due to the use of chickpea flour in the preparation of pasta and also the cold extrusion technique in which temperature below 100⁰ C is used. Temperature acts as an important factor in terms of glycemic index (Maleeka et al., 2020).

4.2.1.2.2.2 Glycemic Load

Table 4.9 clearly depicts the negative impact of chickpea on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) glycemic load reduced from 8.98 to 8.11 with chickpea variation from 15-35 %. Glycemic load showed reducing trend from 5.76 to 4.74 with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. It gets reduced from 7.33 to 6.06 with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from 6.67 to 5.99 at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively. The explanation behind the decrease in glycemic load is due to the increase in the concentration of chickpea in the pasta extrudates. As a result of which the pasta proteins and fibre content increased significantly which in turn increased resistant starch (Suo et al., 2022) and decreased glycemic index as well as glycemic load in the cold pasta extrudates.

4.2.1.2.2.3 Resistant Starch

As depicted from the Table. 4.9, chickpea had positive impact on the resistant starch of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) resistant starch increased from 5.25 to 5.37 with chickpea variation from 15-35 %. Resistant starch showed increasing trend from 7.93 to 8.94 % with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%)

respectively. However, it gets reduced from 6.84 to 6.67 with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed positive effect with chickpea variation of 15-35% from 7.14 to 7.44 at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

4.2.1.2.2.4 Solid Gruel Loss

Chickpea showed negative effect on the solid gruel loss of the sample as per Table: 4.9.

At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) solid gruel loss decreased from 5.06 to 3.05 % with chickpea variation from 15-35 %. It further showed negative trend from 5.88 to 4.66 % with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively and then reduced from 4.37 to 3.67 % with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Solid gruel loss showed again negative effect with chickpea variation of 15-35% from 4.65 to 2.92 % at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

4.2.1.2.2.5 Cooking time

Table: 4.9 depicts that chickpea had positive impact on the cooking time of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) cooking time increased from 2.87 to 4.42 mts. with chickpea variation from 15-35 %. It showed increasing trend from 3.02 to 3.45 mts. with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. Again, it increased from 3.21 to 4.62 mts. with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Solid gruel loss further showed positive effect with chickpea variation of 15-35% from 3.63 to 4.53 mts. at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

4.2.1.2.3 Effect of xanthan gum on the responses (Glycemic index, glycemic load, resistant starch, solid gruel loss and cooking time)

4.2.1.2.3.1 Glycemic index

As depicted from the table 4.9, xanthan gum possessed negative impact on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic index slightly decreased from 32.98 to 32.71 with xanthan gum variation from 1.5-3.5 %.

However, it increased slightly from 29.47 to 29.56 with xanthan gum variation from 1.5-3.5% at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. It gets reduced from 32.19 to 31.84 with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in glycemic index with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (35%) from 31.06 to 31.38 respectively.

4.2.1.2.3.2 Glycemic Load

As depicted from the table 4.9, xanthan gum possessed negative impact on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic load slightly decreased from 7.98 to 7.44 with xanthan gum variation from 1.5-3.5 %. It decreased slightly from 4.47 to 4.10 with xanthan gum variation from 1.5-3.5% at constant concentrations of buckwheat (85%) and chickpea (25%) respectively and further reduced from 7.33 to 6.67 with xanthan gum variation of 1.5-3.5% at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in glycemic load with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (35%) from 6.06 to 5.99 respectively.

4.2.1.2.3.3 Resistant starch

The values of resistant starch from the table 4.9 explained the effect of xanthan gum on the resistant starch. Xanthan gum had a positive effect on the resistant starch of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) resistant starch slightly increased from 5.73 to 5.85 % with xanthan gum variation from 1.5-3.5 %. However, it also increased from 8.68 to 9.09 % with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. Again, it increased from 6.84 to 7.14 % with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in resistant starch with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (35%) from 6.67 to 7.44 % respectively.

4.2.1.2.3.4 Solid gruel loss

As depicted from the table 4.9, xanthan gum had a negative impact on the solid gruel loss of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) solid gruel loss slightly decreased from 4.03 to 3.25 % with xanthan gum variation from 1.5-3.5 %. It again decreased slightly from 4.58 to 4.17 % with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. However, it increased from 4.37 to 4.65 % with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels and reduced afterwards from 3.67 to 2.92 % with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (35%) respectively.

4.2.1.2.3.5 Cooking time

Xanthan gum showed a slight positive effect on the cooking time of the sample as shown in Table 4.9. At constant concentrations of buckwheat (65%) and chickpea (25%) cooking time increased from 4.13 to 4.14 mts. with xanthan gum variation from 1.5-3.5 %. However, it increased slightly from 3.54 to 3.98 mts. with xanthan gum variation from 1.5-3.5 % at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. It increased from 3.21 to 3.63 mts with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it increased with xanthan gum variation from 1.5-3.5% at constant concentrations of buckwheat (75%) and chickpea (35%) from respectively.

4.2.1.3 Model fitness and analysis of variance

Table 4.10 summarizes the analysis of variance (ANOVA) data for different responses indicating the statistical validity. Among different alternate models, the quadratic model was the best fit model for all the responses.

Table 4.10 ANOVA for the fit of data to Response Surface Models

Responses	R²	Adjusted R²	Predicted R²	Adequate Precision	C.V. (%)	p-value	Lack of Fit
Glycemic index	0.9998	0.9996	0.9980	228.82	0.079	0.05	N. S
Glycemic load	0.9979	0.9952	0.9897	70.77	1.37	0.05	N. S
Resistant starch	0.9826	0.9602	0.8638	22.08	3.21	0.05	N. S
Solid gruel loss	0.9503	0.8865	0.7728	13.24	5.17	0.05	N. S
Cooking time	0.9766	0.9466	0.9126	18.46	3.15	0.05	N. S

4.2.1.3.1. Glycemic index

According to Ludwig and Eckel (2002), the glycemic index (GI) is the difference between a test food and a control food, in terms of the area under the blood glucose response curve after consuming a standard amount of carbohydrates from the test food compared to glucose or white bread. According to Table 4.9, G.I. values varied between 29.47 and 33.85, with A representing buckwheat, B representing chickpea, and C representing xanthan gum. In the glycemic index quadratic model, A, B, AB, BC, A², B², and C² were the relevant terms. High F values and $p < 0.0001$ were exhibited by all of them. With a low F-value of 2.64 and a high p-value of 0.1862, the case's lack of fit was not statistically significant. The glycemic response model had R², adjusted R², and predicted R² values of 0.9997, 0.9992, and 0.9956, correspondingly. These factors provide sufficient evidence that the quadratic model is well-fitting. The glycemic index fluctuation of the sample containing buckwheat, chickpea, and xanthan gum may be represented by the following model expression:

$$Y_1 = +31.76 - 1.66A - 0.39B - 0.02C - 0.12AB + 0.09AC + 0.16BC - 0.14A^2 + 0.29AB^2 - 0.43C^2 \quad (14)$$

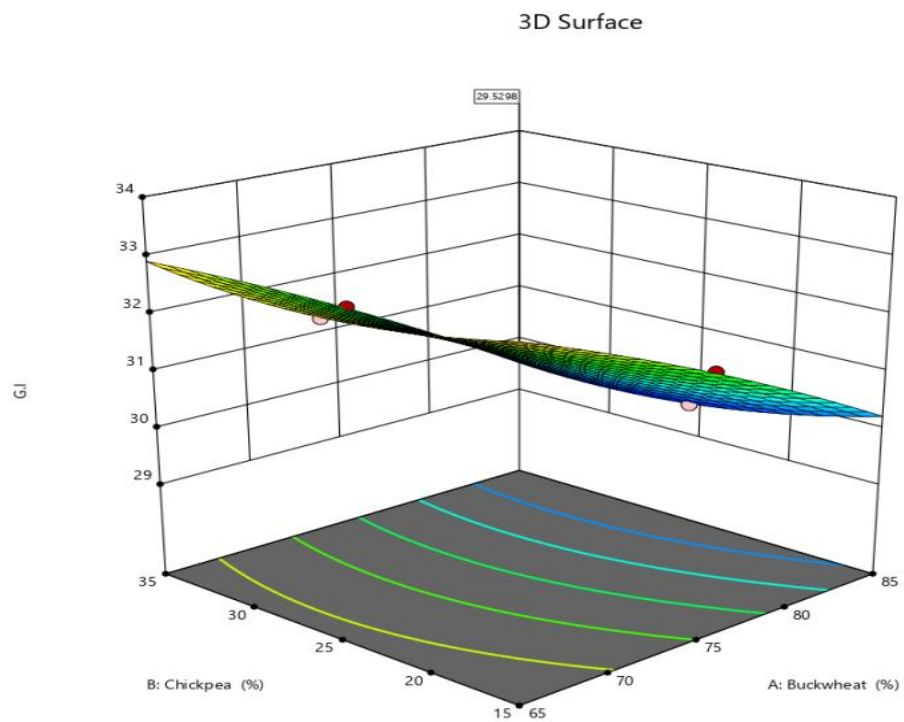


Fig 4.1 Effect of Buckwheat (A) and Chickpea (B) on Glycemic Index

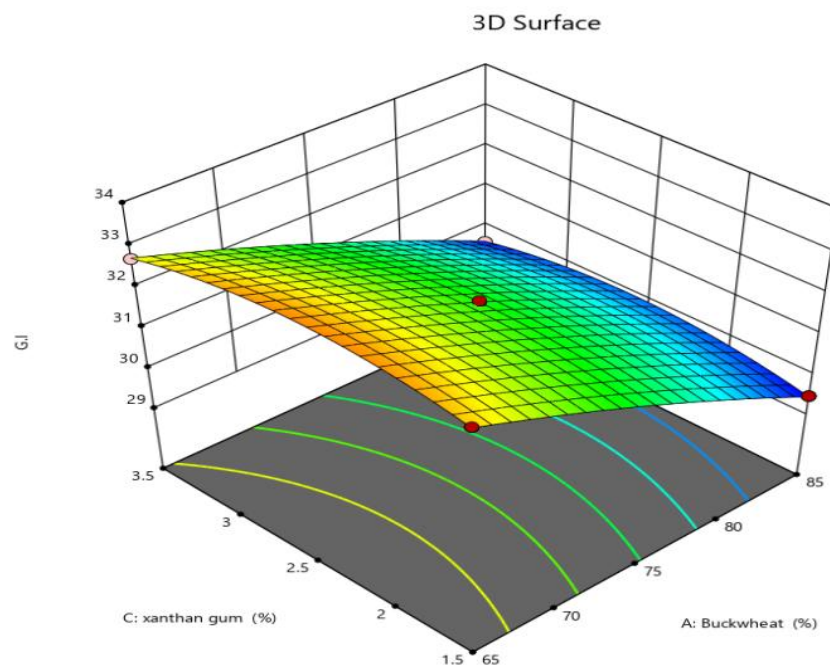


Fig 4.2 Effect of Buckwheat (A) and xanthan gum (C) on Glycemic Index

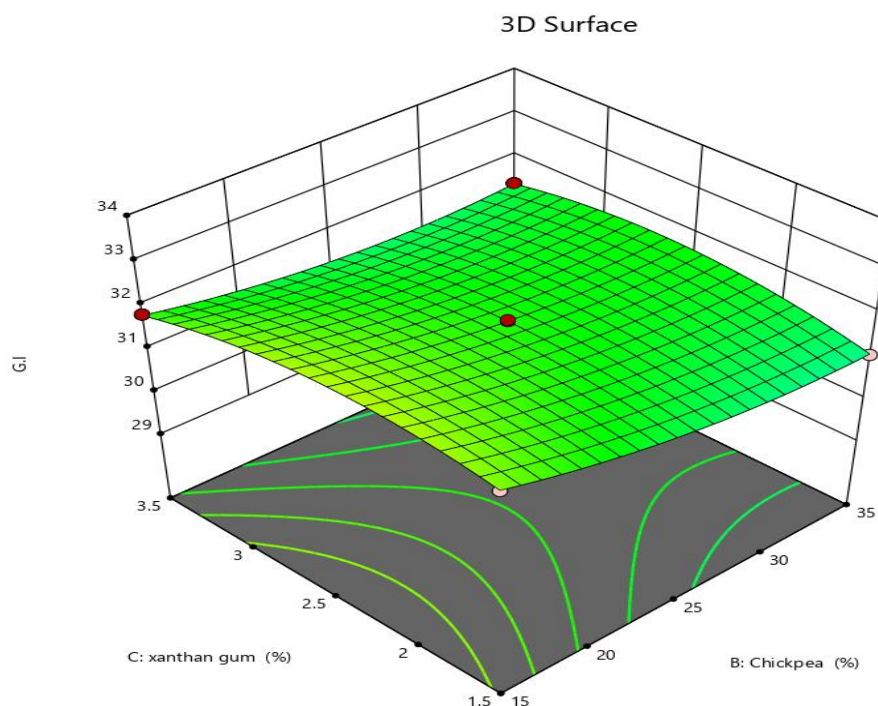


Fig 4.3: Effect of Chickpea (B) and xanthan gum (C) on Glycemic Index

If the linear terms of buckwheat (A), chickpea (B), and xanthan gum (C) have negative coefficients, then an increase in these variables will result in a drop in GI. Because buckwheat has a lower GI value (34.70), adding more buckwheat flour to extrudates causes the GI to fall (Rozanska et al., 2020). In addition, the greater protein contents in chickpeas cause a decrease in GI when their levels are increased. According to Jamiah et al. (2009), proteins alter the digestibility properties of starch by interfering with its absorption by blocking enzyme binding sites. The identical outcomes for pasta with chickpea flour have also been documented by Goni et al. (2003). One way to increase the variety of low GI meals accessible to consumers is by adding low GI pasta proteins to the market. An increase in resistant starch (RS) is responsible for the decrease in GI that occurs with a rise in xanthan gum levels (Naseer et al., 2021). Along with that, hydrocolloids like xanthan gum and carboxy methyl cellulose raise the system's viscosity and coat the surface of starch granules, which restricts the hydrolysis of the granules due to the limited diffusion of α -amylase (Dartoin et al., 2010).

4.2.1.3.2. Glycemic Load

A, B, AB, A², and B² are confirmed as significant factors in the best-fit quadratic model for the glycemic load response variable, with high F values and $p < 0.0001$. Having a high p-value of 0.7619 and an F-value of 0.39. The glycemic load response model has an R² value of 0.9979, an adj R² value of 0.9952, and a predicted R² value of 0.9897. These factors provide sufficient evidence that the quadratic model is well-fitting. The following model expression characterizes the sample's glycemic load fluctuation when treated with buckwheat, chickpea, and xanthan gum:

$$Y_2 = +6.73 - 1.68A - 0.48B - 0.20C - 0.03AB + 0.04AC + 0.14BC - 0.17A^2 + 0.34B^2 - 0.55C^2 \quad (15)$$

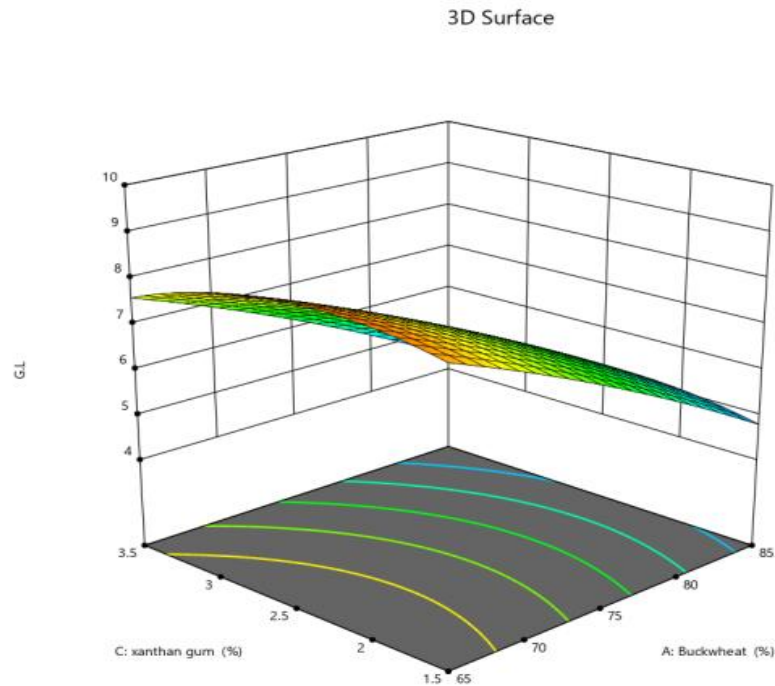


Fig 4.4: Effect of Buckwheat (A) and Chickpea (B) on Glycemic Load

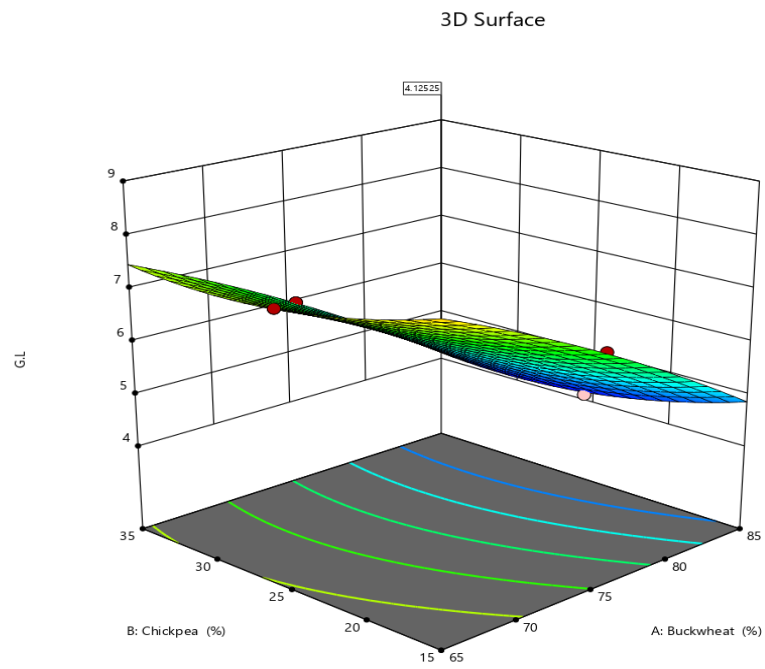


Fig 4.5: Effect of Buckwheat (A) and Xanthan Gum (C) on Glycemic Load

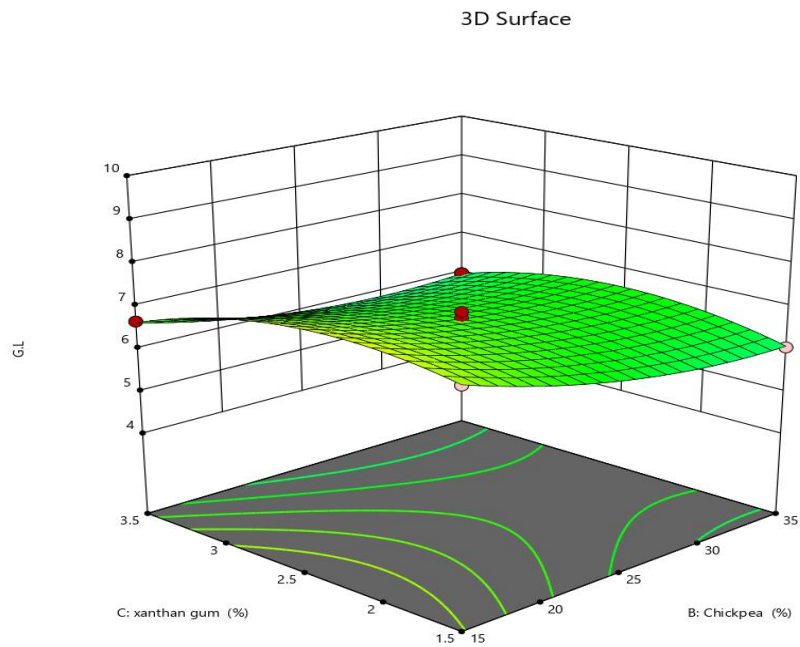


Fig 4.6: Effect of Chickpea (B) and Xanthan Gum(C) on Glycemic Load

Multiplying the quantity of accessible carbs by the glycemic index and then dividing by 100 is the glycemic load. The designed pasta has a glycemic load ranging from 4.10 to 8.98. Due to the positive correlation between the glycemic index and the glycemic load, as well as the fact that, given the right portion size, foods with low glycemic index values can also produce low glycemic load (Parsad et al., 2019). Hence, it was reasonable for the Glycemic Index and Glycemic Load to have comparable behaviour.

4.2.1.3.3. Resistant Starch

Just like that, A, C, and B² are significant factors in the resistant starch quadratic model with high F values and p < 0.0001. A statistically insignificant mismatch (F = 1.02 and p = 0.4720) is what the response model is trying to convey. With an adjusted R² of 0.9602 and a projected R² of 0.8638, the reliability was 0.9826. The model would be ideal if its accuracy value (22.08) was greater than 4. Everything points to the quadratic model being a good match, as stated as:

$$Y_3 = +7.45 + 1.55A + 0.15B + 0.20C + 0.22AB + 0.07AC + 0.11BC - 0.12A^2 - 0.44AB^2 + 0.02C^2 \quad (16)$$

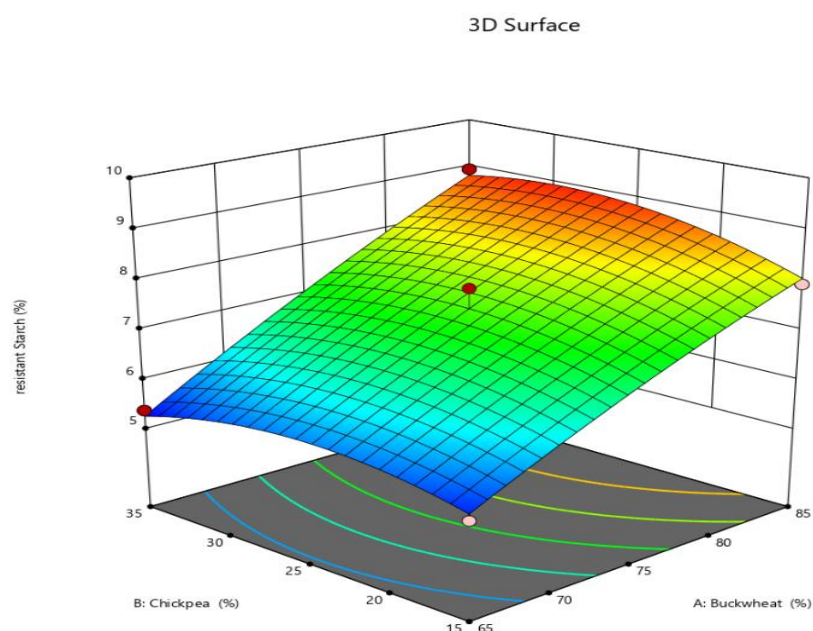


Fig 4.7 Effect of Buckwheat (A) and Chickpea (B) on Resistant Starch

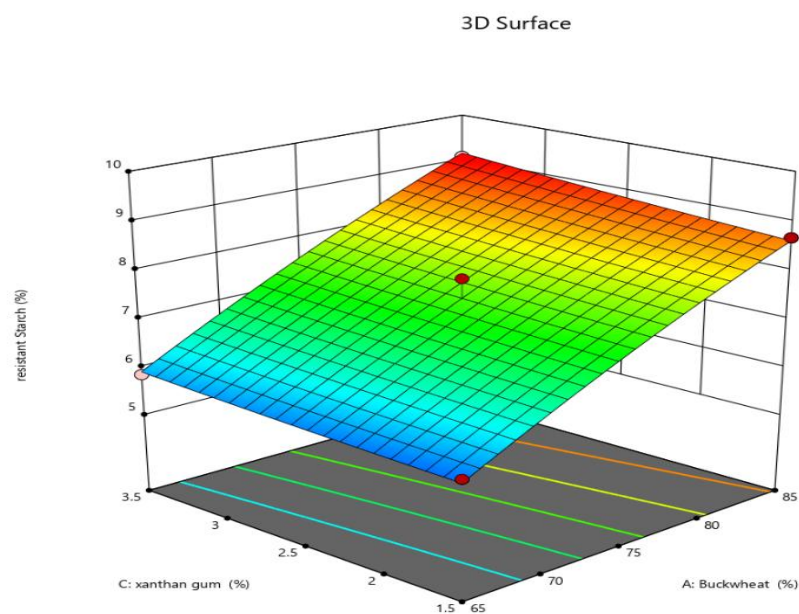


Fig 4.8: Effect of Buckwheat (A) and Xanthan Gum (C) on Resistant Starch

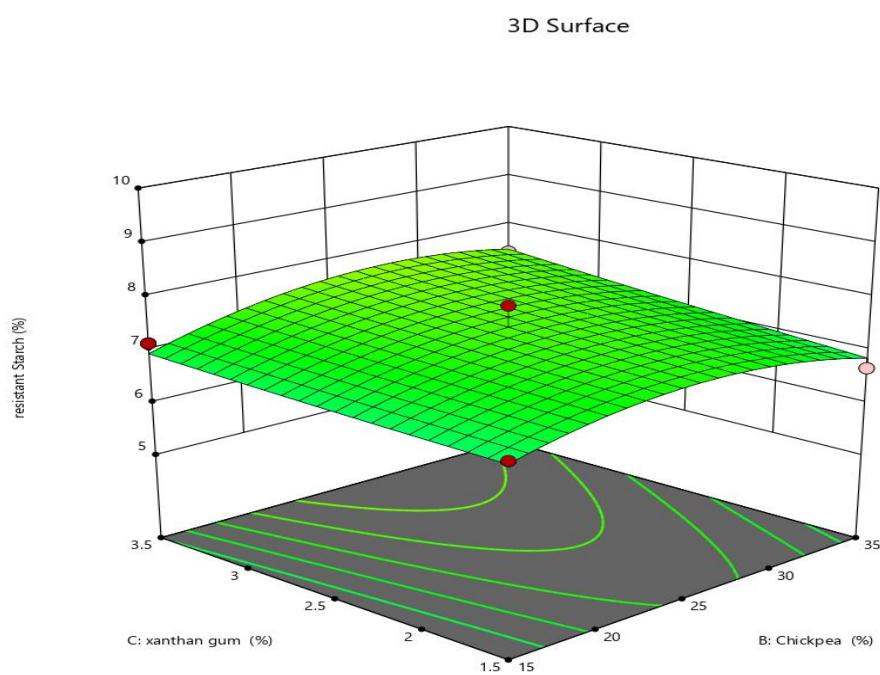


Fig 4.9: Effect of Chickpea (B) and Xanthan Gum (C) on Resistant Starch

The inability of healthy people's small intestines to absorb starch or starch breakdown products is known as resistant starch (RS) (Bjork, 1992). Foods high in carbs provide a glycemic response (GR), and resistant starch is a key component of this GR. Because of the good effects on health, there is a lot of effort to increase the RS content in processed foods (Akerberg et al., 1998). From 5.25 to 9.09, as seen in Table 3.9, RS varied. An increase in resistant starch (RS) was shown by a substantial ($p < 0.0001$) effect of chickpea (B) and buckwheat (A), which was observed as these variables were increased. Buckwheat flour has a greater concentration of RS (3.80%), which may explain why RS increases with increasing buckwheat (A) levels. Chickpea flour amps up the RS level, which may be because the starch and protein combine to make the chickpeas resistant to digestion (Jamilah et al., 2009). According to Ezeogn et al. (2008), the proteins have an effect on how quickly cereals hydrolyze starch. Proteins encase starch granules and block amylolytic enzymes from freely accessing their surface, therefore protecting them from degradation (Rooney and Pflugfelder, 1986). Similarly, due to the gluten in wheat flour, Jenkins et al. (1987) proposed that GR would decrease following ingestion. Starch granules are encased with gluten, which may inhibit starch breakdown in the small intestine.

4.2.1.3.4. Solid gruel loss

Solid gruel loss of pasta is a quality parameter used to evaluate the extent of soluble solid leaching into the cooking water during boiling. Significant terms with high F values and $p < 0.0001$ are confirmed by the best fit quadratic model for the solid gruel loss response variable, which includes A, B, C, AB, and C^2 . Having a high p-value of 0.7917 and an F-value of 0.35. The solid gruel loss response model had R^2 , adjusted R^2 , and predicted R^2 values of 0.9503, 0.8865, and 0.7728, respectively. These factors provide sufficient evidence that the quadratic model is well-fitting. Modeling the sample's solid gruel loss variation using buckwheat, chickpea, and xanthan gum yields the following expression:

$$Y_4 = +4.53 + 0.36A - 0.58B - 0.20C + 0.44AB + 0.09AC - 0.25BC - 0.06A^2 - 0.11B^2 - 0.51C^2 \quad (17)$$

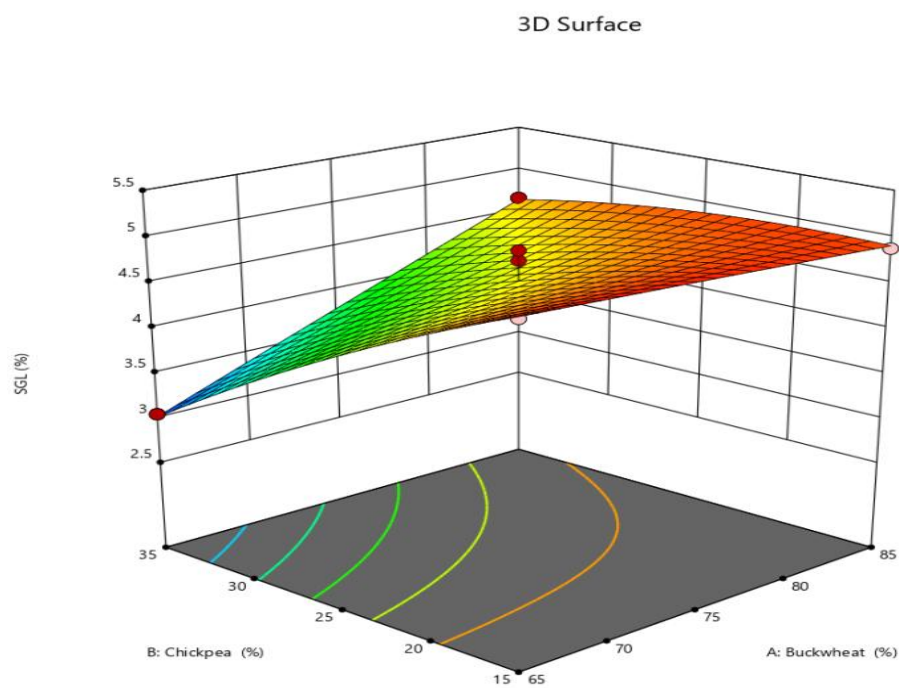


Fig 4.10: Effect of Buckwheat (A) and Chickpea (B) on Solid Gruel Loss

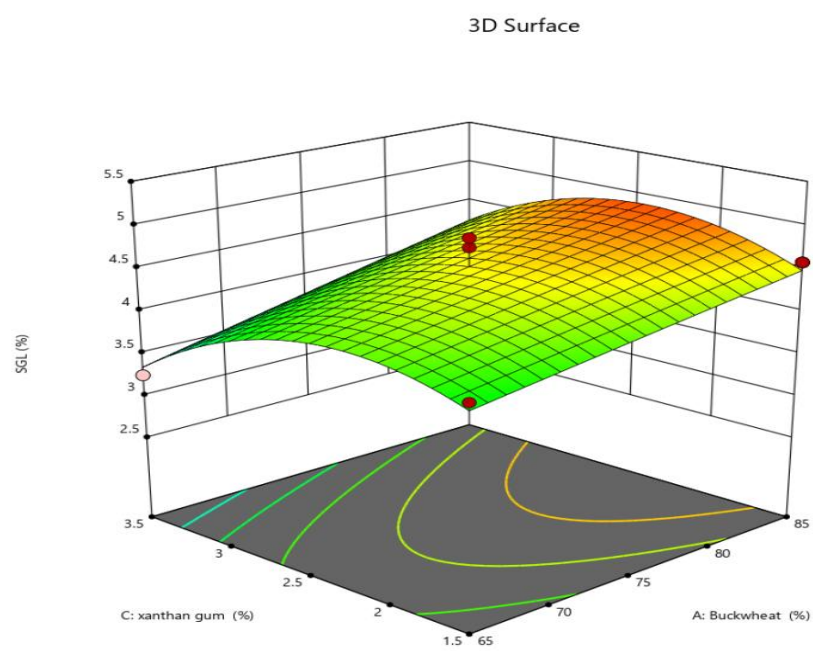


Fig 4.11: Effect of Buckwheat (A) and Xanthan Gum (C) on Solid Gruel Loss

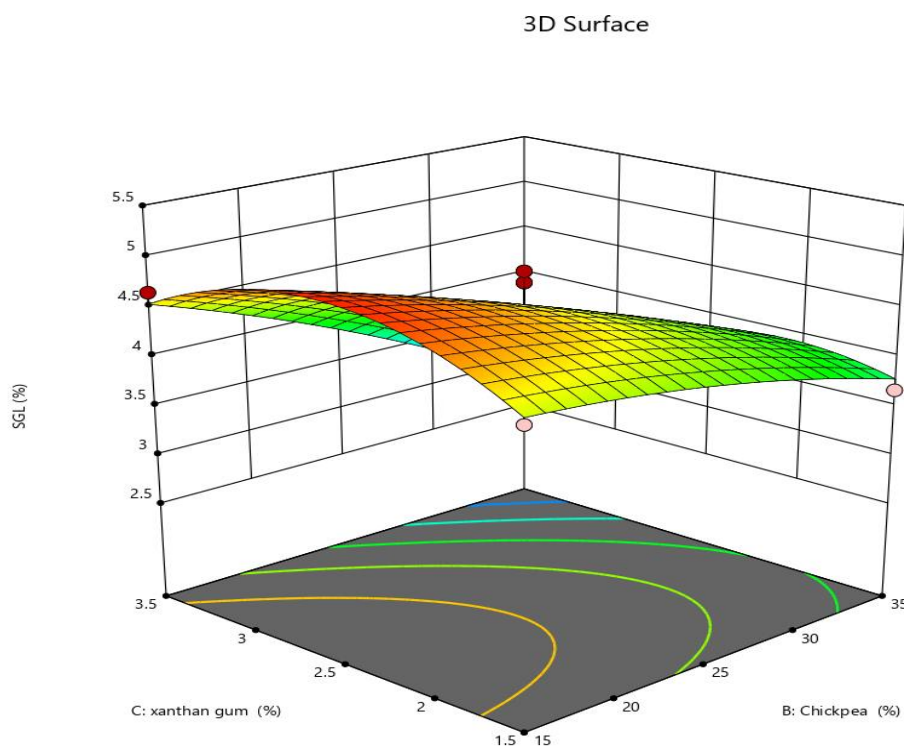


Fig 4.12: Effect of Chickpea (B) and Xanthan Gum (C) on Solid Gruel Loss

A significant ($p < 0.0001$) effect of buckwheat (A) and chickpea (B) could be seen indicating the decrease in solid gruel loss (SGL) with increase in these variables. The rise in solid gruel loss (SGL) with increased concentration of buckwheat (A) could be due to the higher content of resistant starch in buckwheat (3.80%). However, a significant ($p < 0.0001$) possible effect of buckwheat (A) and chickpea (B) could be seen indicating the decrease in solid gruel loss (SGL) with increase in these variables.

4.2.1.3.5. Cooking time

Within the quadratic model for the cooking time response variable, the important terms included A, B, AB, A^2 , B^2 , and C^2 . All of these had significant F values and p-values less than 0.0001. Despite a high p-value of 0.86 and a low F-value of 0.23, the case's lack of fit was minimal. The predictions for the cooking time model were 0.9126, the modified R^2 was 0.9466, and the R^2 value was 0.9766. These factors provide sufficient evidence that the quadratic model is well-fitting. The following is the model expression

that represents the sample's cooking time change using xanthan gum, chickpeas, and buckwheat:

$$Y_5 = +4.20 - 0.19A + 0.53B + 0.09C - 0.28AB + 0.10AC - 0.12BC - 0.40A^2 - 0.35B^2 + 0.15C^2 \quad (18)$$

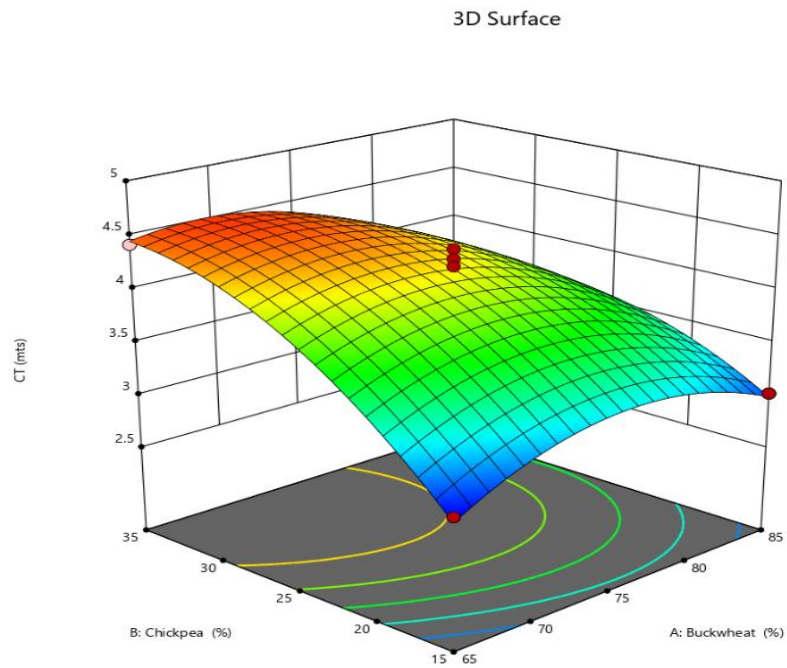


Fig 4.13 Effect of Buckwheat (A) and Chickpea (B) on cooking time

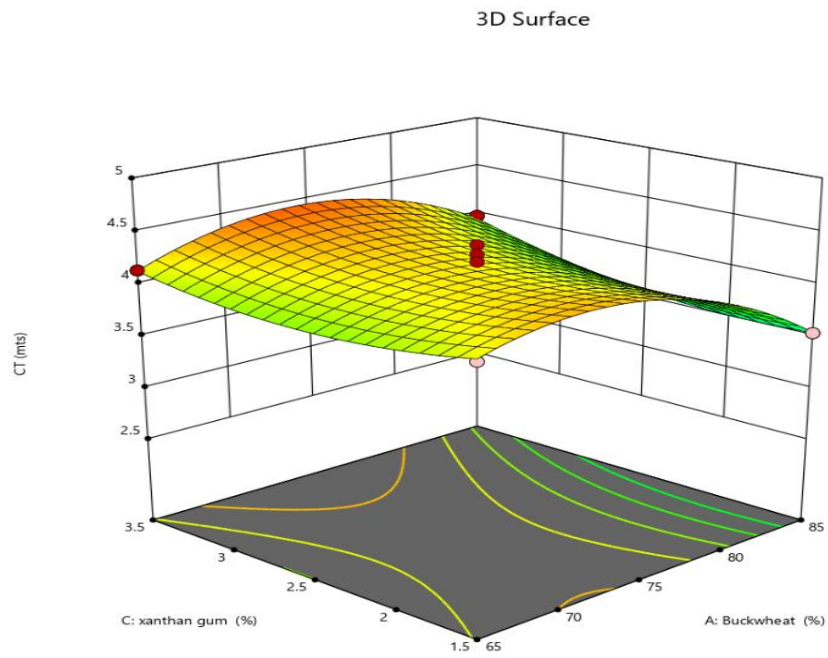


Fig 4.14 Effect of Buckwheat (A) and Xanthan Gum (C) on cooking time

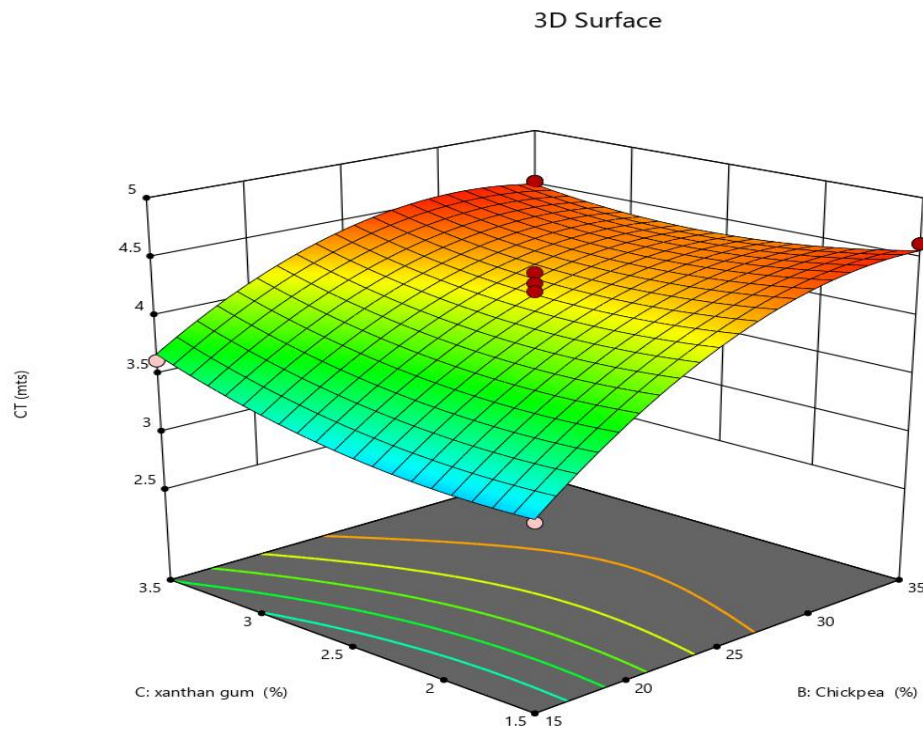


Fig 4.15 Effect of Chickpea (B) and Xanthan Gum (C) on cooking time

4.2.1.4 RSM Optimization and validation of process parameters

For process optimum values, the process variables were optimized using the numerical optimization tool of Design Expert 12.0. Maximizing resistant starch while minimizing glycemic index, glycemic load, solid gruel loss, and cooking time were the guiding principles for the optimization process. We got a desirability value of 0.78. Buckwheat flour (85%), chickpea flour (35%), and xanthan gum (3.50%) were the ideal circumstances for developing low GI extrudates. It is important to note that the values 85%, 35% and 3.50% do not represent percentages but rather indicate the ratio of different ingredients in the RSM formulation. There was a little discrepancy (less than 4%) between the expected and measured response values.

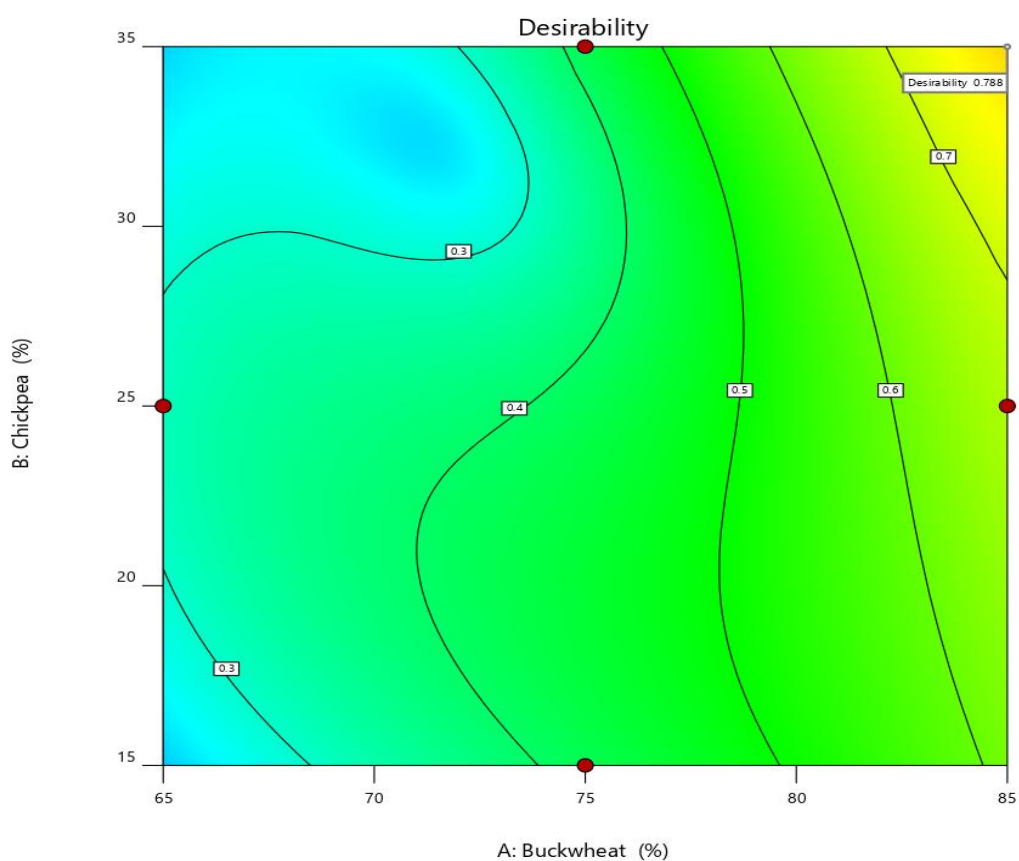


Fig. 4.16: shows the desirability of independent variables.

4.2.2. Carboxymethyl cellulose incorporated extrudates

4.2.2.1: Experimental datasheet

Table 4.11 displays the experimental results collected utilizing BBD of RSM at different buckwheat, chickpea, and carboxymethyl cellulose combinations.

Std	Run	Buck wheat (A) %	Chick pea (B) %	C.M.C (C) %	Glycemic Index (G.I)	Glycemic Load (GL)	Resistant Starch (RS) %	Solid Gruel Loss (SGL) %	Cooking Time (CT) mts.
3	1	65	35	2.5	34.8	9.88	5.88	3.92	4.59
12	2	75	35	3.5	33.41	8.01	7.95	3.79	4.7
2	3	85	15	2.5	32.12	7.72	8.44	5.99	3.19
16	4	75	25	2.5	33.85	8.67	8.36	5.27	4.19
6	5	85	25	1.5	31.92	6.58	9.19	5.45	3.71
15	6	75	25	2.5	33.89	8.59	7.83	5.23	4.39
9	7	75	15	1.5	34.29	9.29	7.35	5.24	3.78
5	8	65	25	1.5	35.03	9.74	6.24	4.28	4.3
7	9	65	25	3.5	35.02	9.4	6.88	4.12	4.31
8	10	85	25	3.5	31.33	6.06	9.55	5.64	4.02
13	11	75	25	2.5	33.86	8.63	8.22	5.62	4.55
17	12	75	25	2.5	33.84	8.86	7.83	5.73	4.24
4	13	85	35	2.5	31.84	6.47	9.45	5.89	3.76
14	14	75	25	2.5	33.85	8.71	7.83	5.15	4.46
10	15	75	35	1.5	33.32	8.02	7.18	4.54	4.79
11	16	75	15	3.5	33.83	8.63	7.65	5.52	3.8
1	17	65	15	2.5	35.95	9.99	5.76	5.93	3.04

Experimental values of the response variables at different combinations of buckwheat, chickpea and carboxymethyl cellulose are presented in Table 4.11. Response surface analysis was used to experimental data using a Statistical Software Design Expert 12

(Stat-Ease Inc. Minneapolis, MN, USA). The second order polynomial response model (equation 2) was fitted to each of the response variable.

4.2.2.2. Effect of process parameters (buckwheat, chickpea and carboxymethyl cellulose) on the responses.

4.2.2.2.1 Effect of buckwheat on glycemic index, glycemic load, resistant starch, solid gruel loss and cooking time.

4.2.2.2.1.1 Glycemic index

The glycemic index of the sample was negatively affected by buckwheat, as shown in table 4.11. With a buckwheat variation of 65–85%, the glycemic index dropped from 34.80 to 31.84 at a constant chickpea (35% concentration) and carboxymethylcellulose (2.5% concentration). Under constant concentrations of chickpea (25%) and C.M.C. (1.5%), the glycemic index decreased from 35.03 to 31.92, whereas buckwheat varied from 65 to 85%. At consistent concentrations of chickpea (25%) and C.M.C. (3.5%), it had a detrimental effect on buckwheat ranging from 35.02 to 31.33, an increase of 65–85%. At a constant concentration of chickpea (15%) and C.M.C. (2.5%), the G.I. values dropped from 35.95 to 32.12, with a buckwheat variance of 65–85%.

4.2.2.2.1.2 Glycemic Load

The glycemic load of the sample was negatively impacted by buckwheat, as shown in table 4.11. Glycemic load decreased from 9.88 to 6.47 with buckwheat variation of 65–85% at constant chickpea (35% of the total) and carboxymethylcellulose (2.5% of the total). With buckwheat ranging from 65 to 85% at constant concentrations of chickpea (25%) and C.M.C. (1.5%), the glycemic load decreased from 9.74% to 6.58%. At constant doses of chickpea (25%) and C.M.C. (3.5%), it had a detrimental impact on buckwheat ranging from 9.40 to 6.06. At a fixed concentration of chickpea (15%) and C.M.C. (2.5%), the glycemic load values decreased from 9.99 to 7.72 with buckwheat variation of 65–85%.

4.2.2.2.1.3 Resistant Starch

As depicted from the table 4.11, buckwheat had a positive effect on the resistant starch of the sample. At constant chickpea (35%) and carboxymethylcellulose (2.5%) resistant starch increased from 5.88 to 9.45 % with buckwheat variation from 65-85 %. Resistant starch showed positive trend from 6.24 to 9.19 % with buckwheat variation from 65-85 % at constant concentrations of chickpea (25%) and C.M.C (1.5%) respectively. It also showed positive effect with buckwheat variation of 65-85% from 6.88 to 9.55 % at constant concentrations of chickpea (25%) and C.M.C (3.5%) respectively. The values of resistant starch were found to be increased from 5.76 to 8.44 % with buckwheat variation of 65-85 % at constant concentration of chickpea (15%) and C.M.C (2.5%) respectively.

4.2.2.2.1.4 Solid Gruel Loss

As depicted from the table 4.11 buckwheat possessed positive impact on the solid gruel loss of the sample. At constant chickpea (35%) and carboxymethylcellulose (2.5%) solid gruel loss increased from 3.92 to 5.89 % with buckwheat variation from 65-85 %. Solid gruel loss showed further positive trend from 4.28 to 5.45 % with buckwheat variation from 65-85 % at constant concentrations of chickpea (25%) and C.M.C (1.5%) respectively. It also showed positive effect with buckwheat variation of 65-85% from 4.12 to 5.64 % at constant concentrations of chickpea (25%) and C.M.C (3.5%) respectively. The values of solid gruel loss were found to be again increased from 5.93 to 5.99 % with buckwheat variation of 65-85% at constant concentration of chickpea (15%) and C.M.C. (2.5%) respectively.

4.2.2.2.1.5 Cooking time

As depicted from the table 4.11 buckwheat possessed negative impact on the cooking time of the sample. At constant chickpea (35%) and carboxymethylcellulose (2.5%) cooking time decreased from 3.92 to 5.89 mts. with buckwheat variation from 65-85 %. Cooking time showed further decreasing trend from 4.30 to 3.71 mins. With buckwheat variation from 65-85 % at constant concentrations of chickpea (25%) and C.M.C (1.5%) respectively. It also showed negative effect with buckwheat variation of 65-85% from 4.12 to 5.64 % at constant concentrations of chickpea (25%) and C.M.C (3.5%) respectively. However, the values of cooking time were found to be

increased from 3.04 to 3.19 mts. with buckwheat variation of 65-85 % at constant concentration of chickpea (15%) and C.M.C. (2.5%) respectively.

4.2.5.2.2 Effect of chickpea on glycemic index, glycemic load, resistant starch, solid gruel loss and cooking time.

4.2.5.2.2.1 Glycemic index

As depicted from the table 4.11, chickpea possessed negative impact on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and C.M.C (2.5%) glycemic index reduced from 35.95 to 34.80 with chickpea variation from 15-35 %. Glycemic index showed reducing trend from 34.29 to 33.32 with chickpea variation from 15-35 % at constant concentrations of buckwheat (75%) and C.M.C (1.5%) respectively. It gets reduced from 33.83 to 33.41 with chickpea variation of 15-35 % at constant buckwheat (75%) and C.M.C (3.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from 32.12 to 31.84 at constant concentrations of buckwheat (85%) and C.M.C (2.5%) respectively.

4.2.5.2.2.2 Glycemic Load

As depicted from the table 4.11, chickpea possessed negative impact on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and C.M.C (2.5%) glycemic load decreased from 9.99 to 9.88 with chickpea variation from 15-35 %. Glycemic load showed reducing trend from 9.29 to 8.02 with chickpea variation from 15-35 % at constant concentrations of buckwheat (75%) and C.M.C (1.5%) respectively. It gets reduced from 8.63 to 8.01 with chickpea variation of 15-35 % at constant buckwheat (75%) and C.M.C (3.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from 7.72 to 6.47 at constant concentrations of buckwheat (85%) and C.M.C (2.5%) respectively.

4.2.5.2.2.3 Resistant starch

As depicted from the table 4.11, chickpea possessed a positive impact on the resistant starch of the sample. At constant concentrations of buckwheat (65%) and C.M.C (2.5%) resistant starch increased from 5.76 to 5.88 % with chickpea variation from 15-35 %.

However, resistant starch showed a slight reducing trend from 7.35 to 7.18 % with chickpea variation from 15-35 % at constant concentrations of buckwheat (75%) and C.M.C (1.5%) respectively. It gets increased from 7.65 to 7.95 % with chickpea variation of 15-35 % at constant buckwheat (75%) and C.M.C (3.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from 8.44 to 9.45% at constant concentrations of buckwheat (85%) and C.M.C (2.5%) respectively.

4.2.5.2.2.4 Solid Gruel Loss

As depicted from the table 4.11, chickpea possessed a negative impact on the solid gruel loss of the sample. At constant concentrations of buckwheat (65%) and C.M.C (2.5%) solid gruel loss decreased from 5.93 to 3.92 % with chickpea variation from 15-35 %. Solid gruel loss showed a slight decreasing trend from 5.24 to 4.54 % with chickpea variation from 15-35 % at constant concentrations of buckwheat (75%) and C.M.C (1.5%) respectively. It further gets decreased from 5.52 to 3.79 % with chickpea variation of 15-35 % at constant buckwheat (75%) and C.M.C (3.5%) concentration levels. However, it showed a slight positive effect with chickpea variation of 15-35% from 5.99 to 5.89 % at constant concentrations of buckwheat (85%) and C.M.C (2.5%) respectively

4.2.5.2.2.5 Cooking Time

As depicted from the table 4.11, chickpea possessed a positive impact on the cooking time of the sample. At constant concentrations of buckwheat (65%) and C.M.C (2.5%) cooking time increased from 3.04 to 4.59 mts. with chickpea variation from 15-35 %. Cooking time showed a slight increasing trend from 3.78 to 4.79 mts. with chickpea variation from 15-35 % at constant concentrations of buckwheat (75%) and C.M.C (1.5%) respectively. It further gets increased from 3.80 to 4.70 mts. with chickpea variation of 15-35 % at constant buckwheat (75%) and C.M.C (3.5%) concentration levels. It continuously showed a slight positive effect with chickpea variation of 15-35% from 3.19 to 3.76 mts. at constant concentrations of buckwheat (85%) and C.M.C (2.5%) respectively.

4.2.5.2.3 Effect of C.M.C on glycemic Index, glycemic load, resistant starch, solid gruel loss and cooking time

4.2.5.2.3.1 Glycemic Index

As depicted from the table 4.11, C.M.C possessed a negative impact on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic index reduced from 35.03 to 35.02 with C.M.C variation from 1.5 - 3.5 %. Glycemic index showed further a slight decreasing trend from 34.29 to 33.83 with C.M.C. variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (15%) respectively. However, it gets increased to very small extent from 33.32 to 33.41 with C.M.C variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (35%) concentration levels. Further, it showed again, a negative effect with C.M.C variation of 1.5-3.5% from 31.92 to 31.33 at constant concentrations of buckwheat (85%) and chickpea (25%) respectively.

4.2.5.2.3.2 Glycemic Load

As depicted from the table 4.11, C.M.C possessed a negative impact on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic load reduced from 9.74 to 9.40 with C.M.C variation from 1.5-3.5 %. Glycemic load showed further a slight decreasing trend from 9.29 to 8.63 with C.M.C variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (15%) respectively. It gets decreased to very small extent from 8.02 to 8.01 with C.M.C variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (35%) concentration levels. Further, it showed again, the negative effect with C.M.C variation of 1.5-3.5% from 6.58 to 6.06 at constant concentrations of buckwheat (85%) and chickpea (25%) respectively.

4.2.5.2.3.3 Resistant Starch

As depicted from the table 4.11, C.M.C possessed a positive impact on the resistant starch of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) resistant starch increased from 6.24 to 6.88 % with C.M.C variation from 1.5 - 3.5 %. Resistant starch showed further a slight increasing trend from 7.35 to 7.65 %

with C.M.C variation from 1.5-3.5 % at constant concentrations of buckwheat (75%) and chickpea (1.5%) respectively. It gets increased to very small extent from 7.18 to 7.95 % with C.M.C variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (35%) concentration levels. Further, it showed again, a positive effect with C.M.C variation of 1.5 – 3.5% from 9.19 to 9.55 % at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. This could be due to the interference of C.M.C with the retrogradation of starch molecules.

4.2.5.2.3.4 Solid Gruel Loss

Table 4.11 shows that the solid gruel loss of the sample was negatively affected by C.M.C. While C.M.C varied between 1.5% and 3.5%, solid gruel loss decreased from 4.28 to 4.12% at constant buckwheat (65%) and chickpea (25%). This is because the dough's water-holding ability was enhanced by adding C.M.C, which possesses water-binding capabilities. This causes the dough to retain more water, which in turn increases the water activity. This might affect the pasta's texture, shelf life, and the loss of solid gruel. Contrarily, at constant buckwheat (75% concentration) and chickpea (15%) concentrations, it exhibited a little rising trend from 5.24% to 5.52% with C.M.C fluctuation between 1.5-3.5%. Potentially to blame is the reduced chickpea concentration 15% rather than 25% like in the previous mix. The solid gruel loss increased because the pasta leaches out too much solids because of its inadequate protein network. Alternatively, with constant concentrations of buckwheat (75% and 35% respectively) and chickpea (35%), it drops from 4.54% to 3.79% with a C.M.C fluctuation of 1.35% to 3.50%. In addition, at constant concentrations of buckwheat (85%) and chickpea (25%), it had a small favorable impact with a change of 1.5-3.5% in C.M.C from 5.45% to 5.64 %. Solid gruel loss values ranged from 3.79 to 5.99 across all of the extrudate combinations tested (Table 4.11). The numbers vary for a good reason: when C.M.C concentrations are high, a gum network forms around the starch granules in extruded pasta, limiting the swelling and cooking of the pasta. In a similar way, Chillo et al. (2007) discovered that increasing the carboxymethylcellulose content of spaghetti reduced solid gruel loss.

4.2.5.2.3.5 Cooking Time

Table 4.11 shows that the sample required less cooking time when C.M.C was used. The cooking time increased from 4.30 to 4.31 mts. at a constant concentration of 65% buckwheat and 25% chickpea, with a change in C.M.C of 1.5-3.5 percent. Constant buckwheat (75% concentration) and chickpea (15%) concentrations resulted in somewhat longer cooking times (3.78 to 3.80 mts), but the C.M.C ranged from 1.5 to 3.5%. However, when the C.M.C is changed from 1.5% to 3.5%, it decreases from 4.79 to 4.70 mts. when the concentration is maintained at 75% buckwheat and 35% chickpea. Furthermore, it showed a little positive effect with a 1.5-3.5% shift in C.M.C from 3.71 to 4.02 mts, when buckwheat concentrations were kept constant at 85% and chickpea at 25%.

4.2.2.3. Model fitness and analysis of variance

Table 4.12 presents summary of analysis of variance (ANOVA) for different responses, highlighting the statistical significance. The analysis identified the quadratic model as the most suitable fit for all the responses among the various alternative models.

Table 4.12 ANOVA for the fit of data to Response Surface Models.

Responses	R ²	Adjusted R ²	Predicted R ²	Adequate Precision	C.V. (%)	p-value	Lack of Fit
Glycemic index	0.9997	0.9992	0.9956	173.60	0.10	0.05	N. S
Glycemic load	0.9924	0.9827	0.9074	33.53	1.83	0.05	N. S
Resistant starch	0.9784	0.9506	0.8417	19.80	3.24	0.05	N. S
Solid gruel loss	0.9570	0.9017	0.7648	13.23	4.44	0.05	N. S
Cooking time	0.9702	0.9320	0.8475	16.79	3.18	0.05	N. S

As evidence of the statistical validity, Table 4.12 displays various data associated to analysis of variance for various replies. All of the product responses (glycemic index, glycemic load, resistant starch, solid gruel loss, and cooking time) were shown to have significant models with high coefficients of determination ($R^2=0.9570-0.9997$) and a p-value of less than or equal to 0.001. To guarantee a fair match between empirical models and real data, the calculated coefficients of determination for all the chosen parameters were very desired. All of the product answers showed very good agreement between the expected and modified R^2 values. Coefficients of variation (CV), which show how well and consistently the models performed, varied between 0.10% and 4.44%.

All of the models showed a very good acceptable precision range (13.23-173.60), which means that the model discrimination was sufficient for all of the parameters. The second-order polynomial models agreed well with the observed data, as there was no statistically significant mismatch between the models for any of the parameters.

Here, it is crucial to note that only those independent factors were included in the models for each dependent variable that had a substantial influence, as shown by the ANOVA findings.

4.2.2.3.1 Glycemic index

The glycemic index (GI) measures the change in blood glucose levels following the consumption of a standard amount of carbohydrates from the test food compared to a control food (white bread or glucose) (Ludwig and Eckel, 2002). In this study, the GI ranged from 31.33 to 35.95 (Table 4.11), with A representing buckwheat, B representing chickpea, and C representing carboxymethyl cellulose.

The significant factors in the quadratic model for the glycemic index included A, B, C, AB, AC, BC, A^2 , B^2 , and C^2 . These terms exhibited high F-values and low p-values (< 0.0001). The lack of fit was not significant, as indicated by a low F-value (6.15) and a high p-value (0.0559). The model's goodness of fit was further supported by R^2 , Adj R^2 , and Pred R^2 values of 0.9997, 0.9992, and 0.9956, respectively. The quadratic

model is thus considered a good fit for representing the variations in glycemic index based on the combination of buckwheat, chickpea, and carboxymethyl cellulose.

$$Y_1 = +33.86 - 1.70A - 0.35B - 0.12C - 0.12AB + 0.14AC + 0.13BC - 0.28A^2 + 0.10AB^2 - 0.24C^2 \quad (19)$$

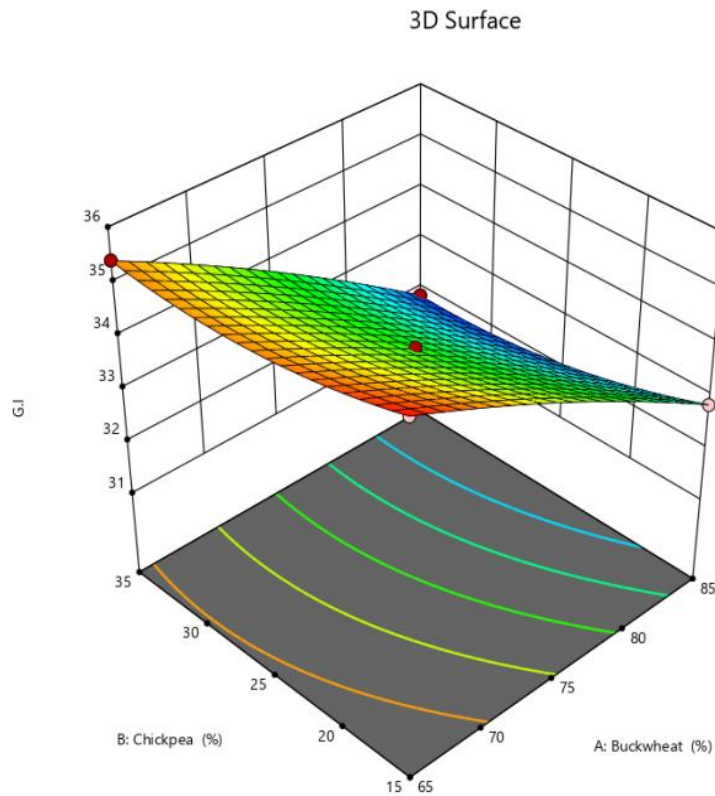


Fig 4.17: Effect of Buckwheat (A) and Chickpea (C) on GI

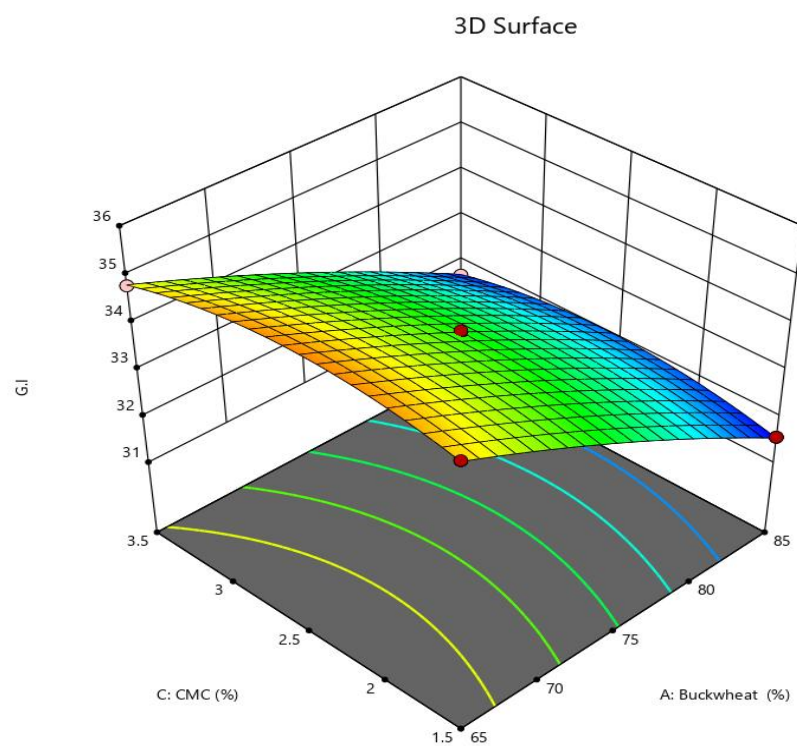


Fig 4.18: Effect of Buckwheat (A) and C.M.C (C) on GI

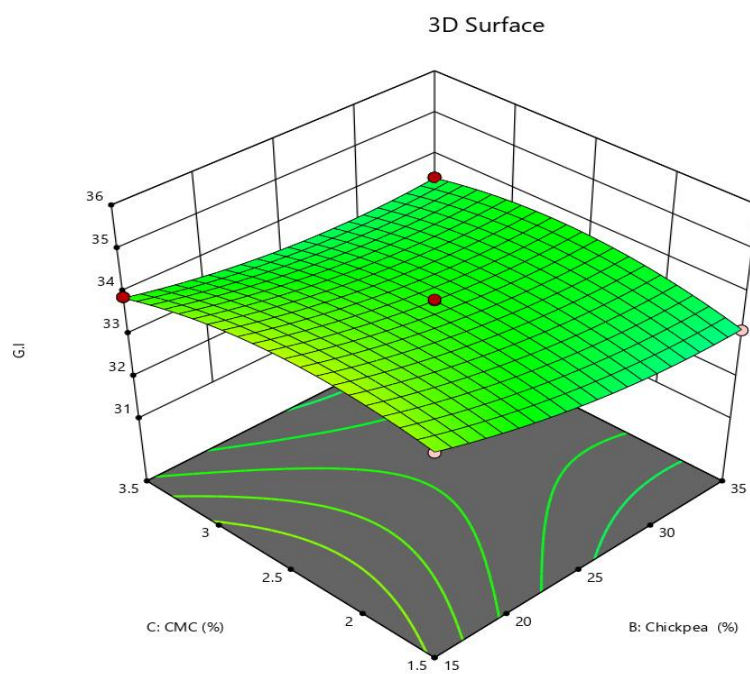


Fig 4.19: Effect of Chickpea (B) and C.M.C (C) on GI

4.2.2.3.2 Glycemic load

For the quadratic model of glycemic load, the significant terms identified were A, B, CAB, A², B², and C², which showed high F-values and p-values < 0.0001. The model demonstrated an insignificant lack of fit, with an F-value of 3.81 and a p-value of 0.1145. The R², adjusted R², and predicted R² values were 0.9924, 0.9827, and 0.9074, respectively. The model's adequate precision value of 33.53, which exceeds the desired threshold of 4, further supports its validity. These indicators collectively confirm the suitability of the quadratic model for representing the variations in glycemic load based on the combination of buckwheat, chickpea, and carboxymethyl cellulose.

$$Y_2 = +8.69 - 1.52A - 0.40B - 0.19C - 0.28AB + 0.04AC + 0.16BC - 0.35A^2 + 0.18AB^2 - 0.24C^2 \quad (20)$$

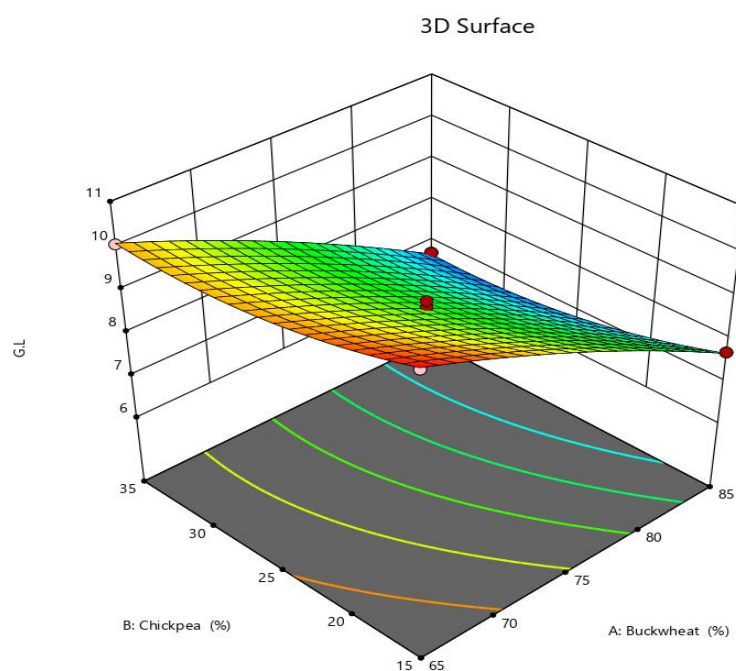


Fig 4.20: Effect of Buckwheat (A) and Chickpea (B) on GL

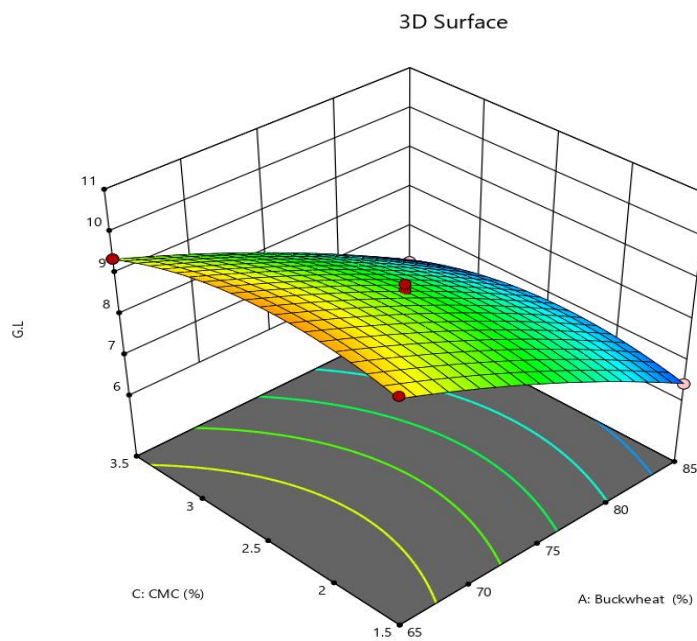


Fig 4.21: Effect of Buckwheat (A) and C.M.C (C) on GL

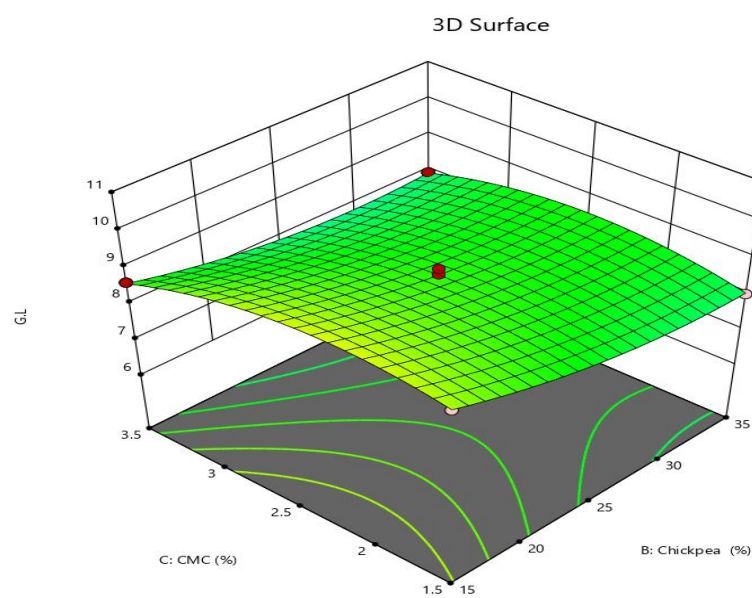


Fig 4.22 Effect of Chickpea (B) and C.M.C (C) on GL

4.2.2.3.3 Resistant starch

For the quadratic model of resistant starch, the significant terms identified were A, C, and B², which exhibited high F-values and a p-value < 0.0001. The model showed an insignificant lack of fit, with an F-value of 0.88 and a p-value of 0.5205. The R², adjusted R², and predicted R² values were 0.9784, 0.9506, and 0.8417, respectively. The model's adequate precision value of 19.80, which exceeds the desired threshold of 4, indicates a good fit. These metrics collectively validate the effectiveness of the quadratic model for representing variations in resistant starch.

$$Y_3 = +8.01 - 1.48A - 0.15B - 0.25C - 0.22AB + 0.07AC + 0.11BC - 0.09A^2 + 0.53AB^2 - 0.05C^2 \quad (21)$$

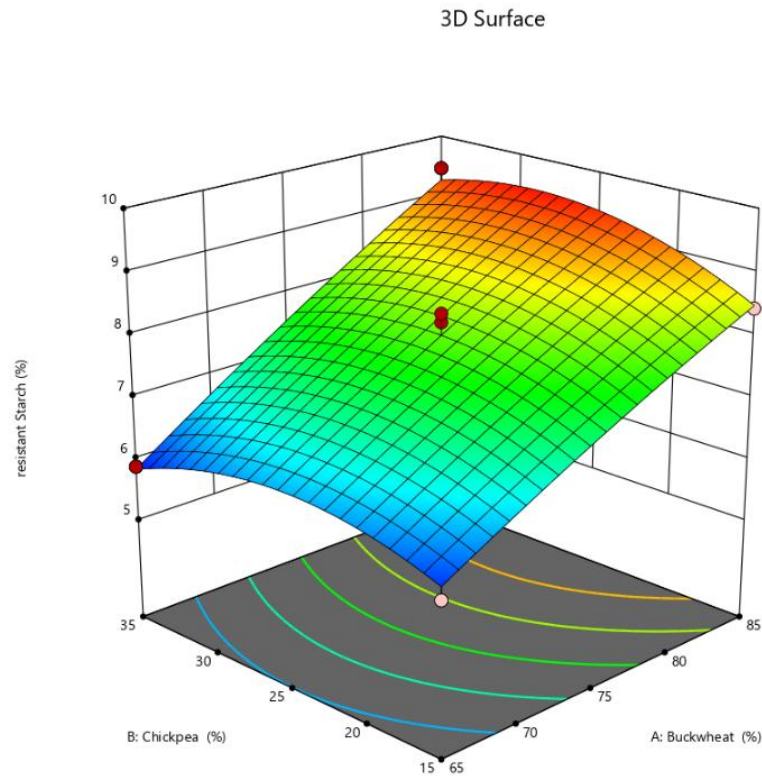


Fig 4.23: Effect of Chickpea (A) and Buckwheat (B) on Resistant Starch

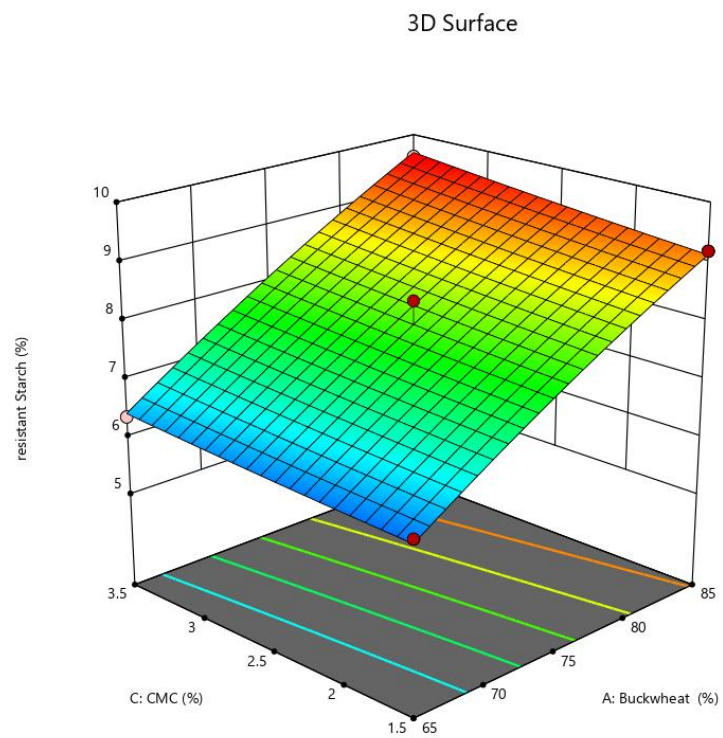


Fig 4.24: Effect of Buckwheat (A) and C.M.C (C) on Resistant Starch

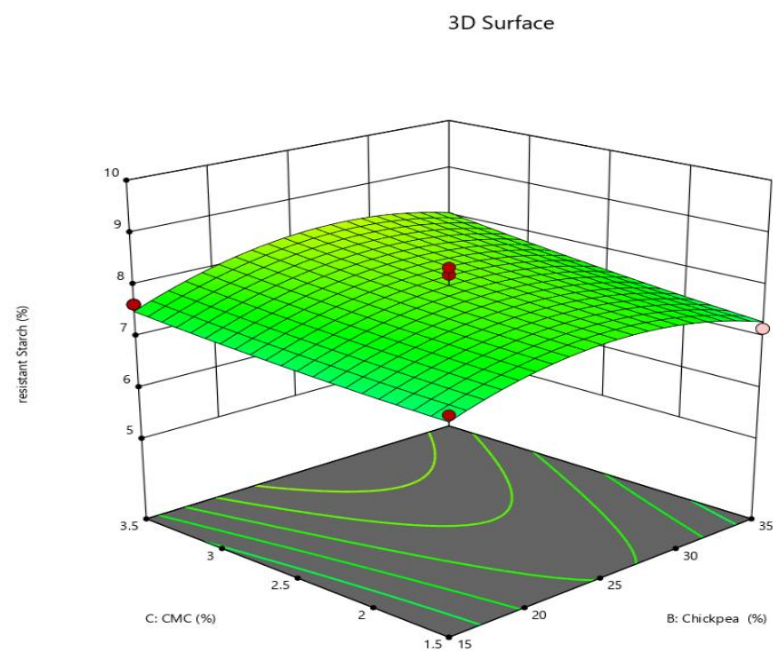


Fig 4.25: Effect of Chickpea(B) and C.M.C (C) on Resistant Starc

4.2.2.3.4 Solid gruel loss

The quadratic model that best fits the solid gruel loss response variable identifies A, B, AB, and C² as significant terms, each with high F-values and a p-value < 0.0001. The model's lack of fit was insignificant, with an F-value of 0.49 and a p-value of 0.7053. The R², adjusted R², and predicted R² values for this model were 0.9570, 0.9017, and 0.7648, respectively, indicating a good fit. The model expression for representing variations in solid gruel loss with buckwheat, chickpea, and carboxymethyl cellulose is as follows:

$$Y_4 = +5.40 - 0.56A - 0.56B - 0.05C - 0.47AB + 0.08AC + 0.25BC - 0.06A^2 + 0.03AB^2 - 0.593C^2 \quad (22)$$

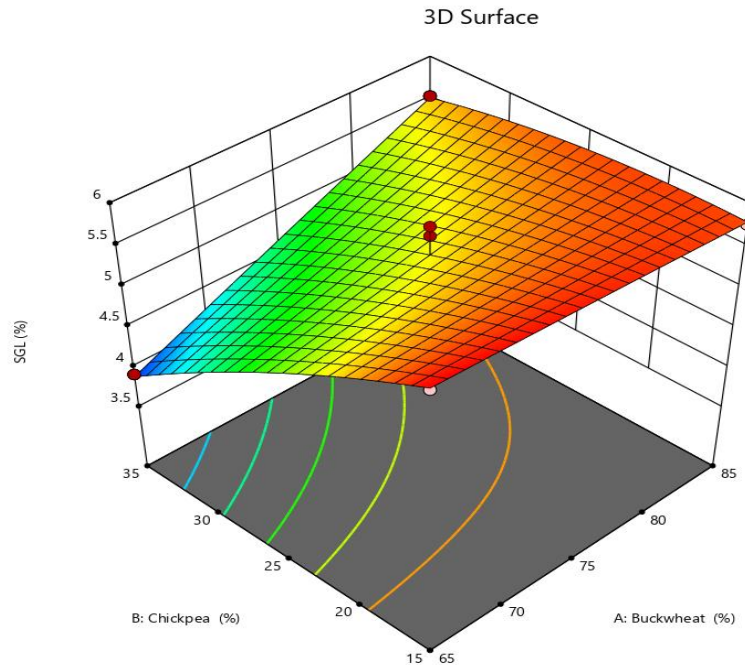


Fig 4.26: Effect of Buckwheat (A) and Chickpea (B) on Solid Gruel Loss

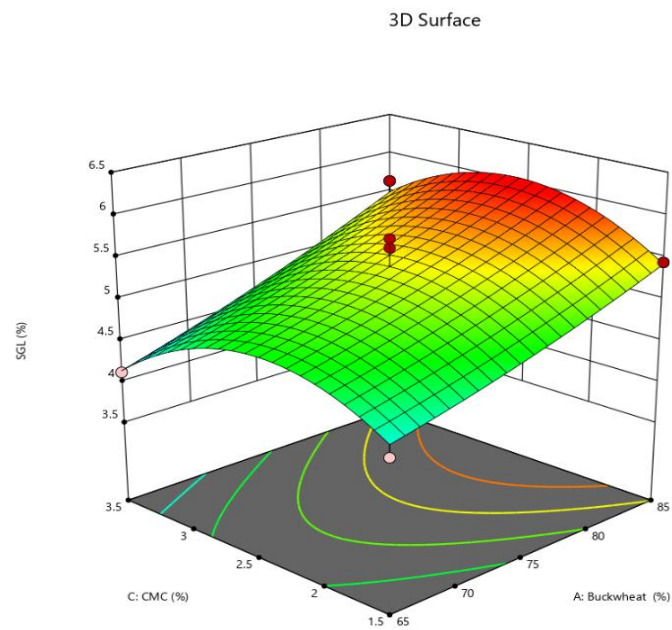


Fig 4.27: Effect of Buckwheat (A) and C.M.C (C) on Solid Gruel Loss

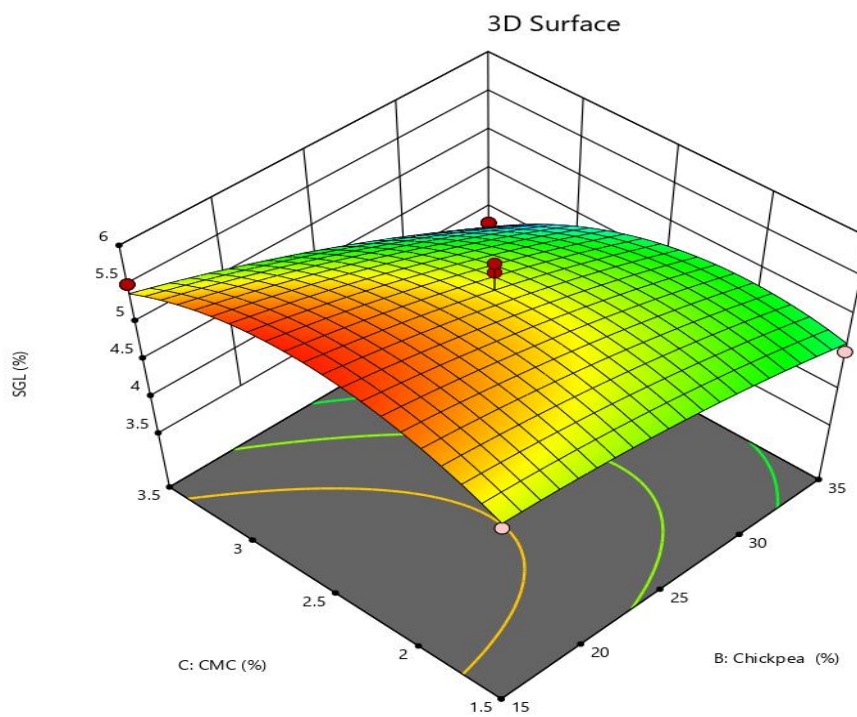


Fig 4.28: Effect of Chickpea (B) and C.M.C (C) on Solid Gruel Loss

4.2.2.3.5 Cooking time

The quadratic model for the cooking time response variable identifies A, B, AB, A², B², and C² as significant terms, all with high F-values and a p-value < 0.0001. The lack of fit was minimal, with an F-value of 0.43 and a p-value of 0.7389. The R², adjusted R², and predicted R² values for this model were 0.9702, 0.9320, and 0.8475, respectively, indicating a strong fit. The model expression for depicting variations in cooking time with buckwheat, chickpea, and carboxymethyl cellulose is as follows:

$$Y_5 = +4.37 - 0.19A - 0.50B - 0.03C - 0.24AB + 0.07AC + 0.02BC - 0.45A^2 + 0.26AB^2 - 0.05C^2 \quad (23)$$

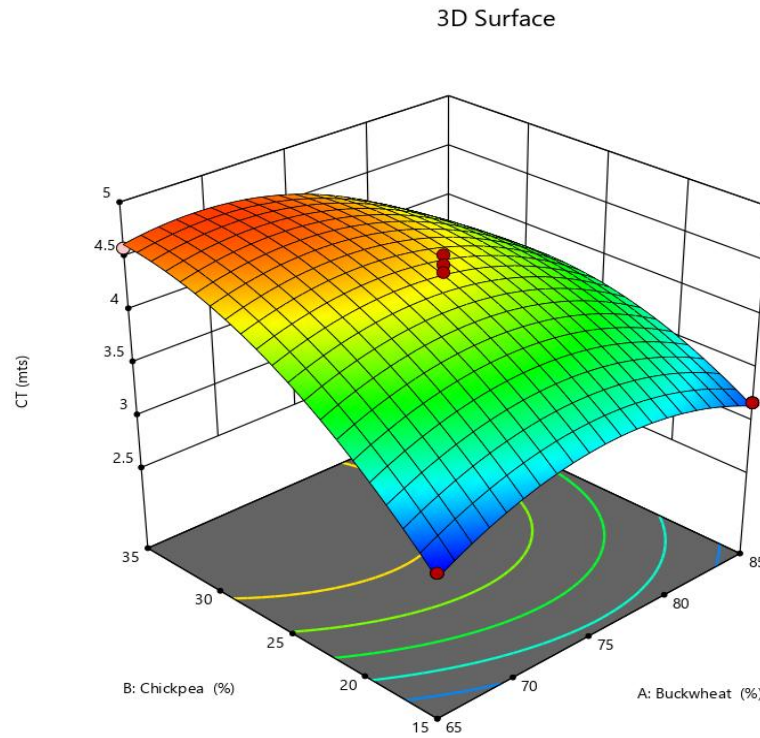


Fig 4.29: Effect of Buckwheat (A) and Chickpea (B) on Cooking Time

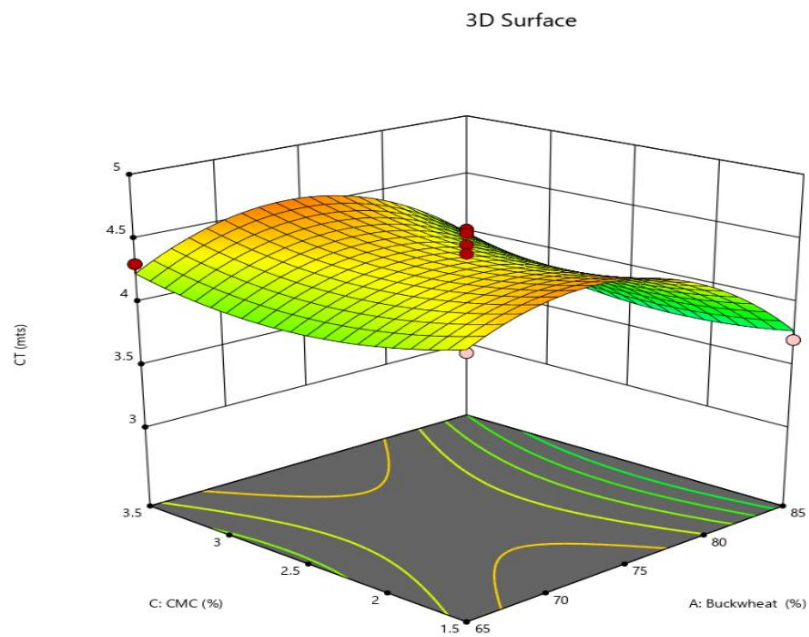


Fig 4.30: Effect of Buckwheat (A) and C.M.C (C) on Cooking Tim

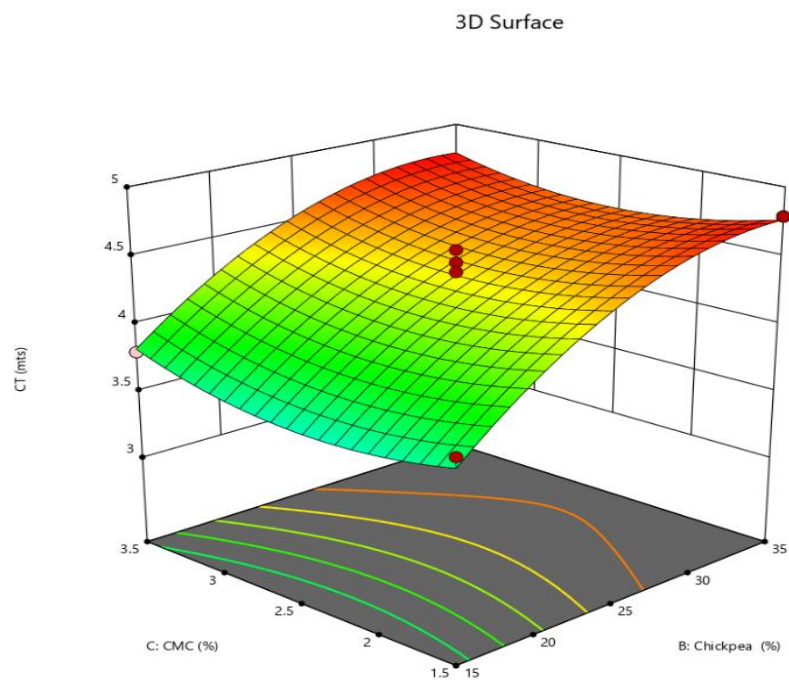


Fig. 4.31: Effect of Chickpea (B) and C.M.C (C) on Cooking Time

4.2.2.4. Response surface analysis

There was a substantial effect of variation in buckwheat, chickpea, and carboxymethyl cellulose on all response variables, as well as on their square terms and interaction terms ($p \leq 0.0004$). Viewed in Figures 4.17-4.31 are the response plots for G.I, G.L, R.S, S.G.L, and C.T.

4.2.2.5. RSM Optimization and model validation

By utilizing the desirability function approach, the ideal state was achieved. The obtained desirability value was 0.71. Flour made from buckwheat (85%), chickpeas (35%), and carboxymethyl cellulose (3.5%) yielded the best pasta. The difference between the expected and observed response values was less than 4%, which is quite close.

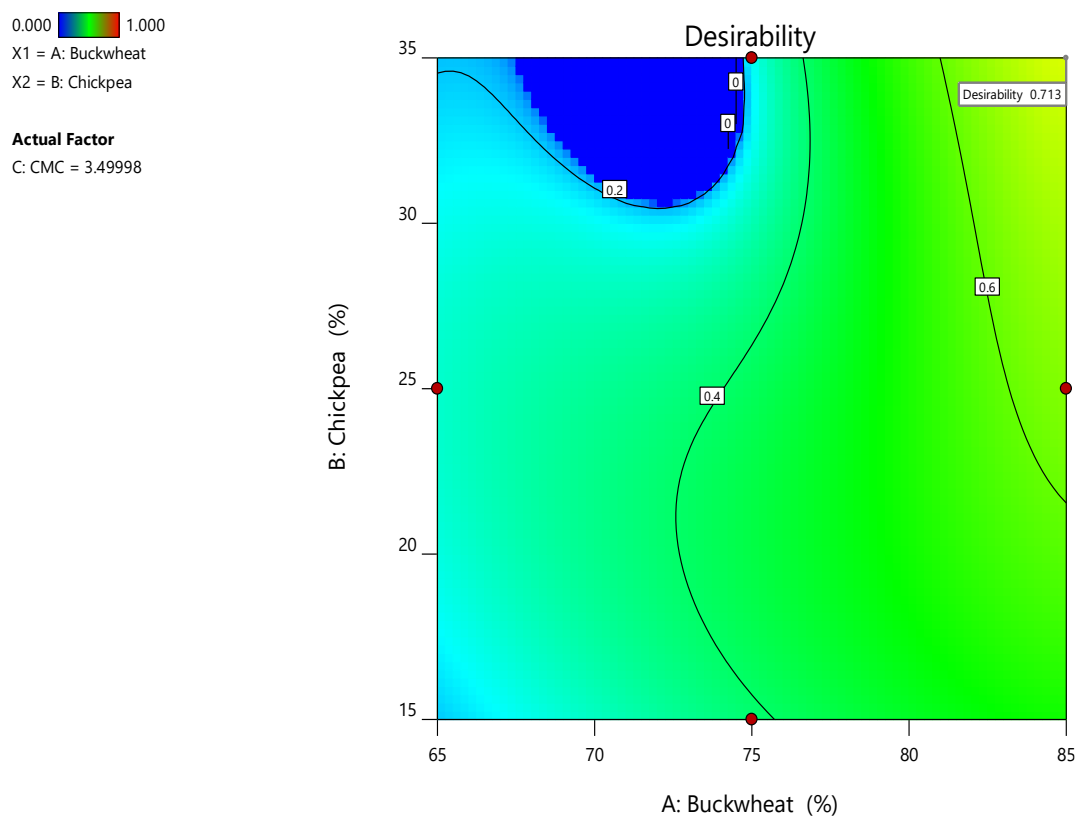


Fig. 4.32: Desirability Graph

4.2.3. Physicochemical characterization of developed extrudates

4.2.3.1 Xanthan gum incorporated extrudates

4.2.3.1.1 Proximate composition

Table 4.13 displays the findings of the proximate composition of the pasta that has xanthan gum added to it. The results show that the pasta with xanthan gum added had a considerably higher moisture content ($3.71 \pm 0.75\%$) compared to the control ($6.11 \pm 0.86\%$). Results for wheat-based pasta added with buckwheat flour were comparable to those reported by Sultan et al. (2020). Xanthan gum pasta also had considerably greater concentrations of crude protein, ash, crude fat, and crude fiber ($p < 0.05$) compared to the control. Sultan et al. (2020) found that when wheat bread pasta is made with buckwheat, these factors go up. Due to the increased levels of protein-rich chickpea flour in the xanthan gum incorporated extrudates, carbohydrates were considerably ($p < 0.05$) higher in the control than in the xanthan gum integrated pasta. The control had a higher energy value of 318.47 ± 2.23 Kcal/100 g, whereas the xanthan gum pasta had a substantially higher value of 328.63 ± 2.70 Kcal/100 g. This is because xanthan gum pasta has more fat and protein than regular pasta.

Both the control and pasta with xanthan gum added had water activities that were lower than what is needed for microbial development, but they were still within the range that indicates both pasta and xanthan gum are shelf stable (0.25 ± 0.01 vs. 0.39 ± 0.03).

Table 4.13 Presents proximate composition of xanthan gum incorporated extrudates

S. No.	Parameter	Control extrudates	XG incorporated extrudates
1.	Moisture (%)	6.11 ± 0.86	3.71 ± 0.75
2.	Crude protein (%)	16.16 ± 0.91	17.01 ± 0.19
3.	Crude fat (%)	3.03 ± 0.32	3.51 ± 0.24
4.	Ash (%)	1.12 ± 0.19	1.78 ± 0.05
5.	Crude fiber (%)	11.82 ± 0.97	10.60 ± 0.05
6.	Carbohydrates (%)	61.76 ± 1.28	63.39 ± 1.20
7.	Energy (Kcal/100g)	318.47 ± 2.26	328.63 ± 2.70
8.	Water activity (a_w)	0.39 ± 0.03	0.25 ± 0.01

Values are shown as mean $\pm$ standard deviation.

Table 4.14: Total sugars, reducing sugars and non-reducing sugars of xanthan gum incorporated extrudates

Table 4.14 reflects the values of total sugars, reducing sugars, and non-reducing sugars. The sugar profile of the pasta with and without xanthan gum is shown. There was no statistically significant difference ($P>0.05$) between the control and xanthan gum pasta groups in terms of various sugars.

S. No.	Parameter	Control	Xanthan Gum
1.	Total sugars	0.07 ± 0.02	0.04 ± 0.01
2.	Reducing sugars	0.002 ± 0.00	0.001 ± 0.00
3.	Non -Reducing sugars	0.05 ± 0.02	0.039 ± 0.01

4.2.3.1.2 Minerals

Compared to the control, xanthan gum had a considerably greater mineral content ($p<0.05$). The results showed the appropriate concentrations of calcium, iron, magnesium, and zinc were 187.97 ± 5.03 mg/100 g, 110.48 ± 1.30 mg/100 g, 85.71 ± 0.93 mg/100 g, and 94.83 ± 0.31 mg/100 g, respectively. The greater mineral content of xanthan gum pasta, which is statistically significant ($p<0.05$), may be attributable to the higher mineral content of buckwheat and chickpea flour, which in turn causes higher ash levels. According to Sultan (2020). Table 4.13 of the Proximate composition provides strong support for our findings, as the ash and mineral levels are positively comparable.

Table 4.15 presents minerals of xanthan gum incorporated pasta extrudates

S.No.	Minerals (mg/100 g)	Control	Xanthan gum
1.	Calcium	178.62 ± 3.21	187.97 ± 5.03
2.	Iron	103.28 ± 0.18	110.48 ± 1.30
3.	Magnesium	80.62 ± 0.36	85.71 ± 0.93
4.	Zinc	90.51 ± 0.48	94.83 ± 0.31

4.2.3.1.3 Total starch, resistant starch, dietary fibre, available carbohydrates, glycemic index and glycemic load of xanthan gum incorporated pasta extrudates.

Table 4.16. gives a rundown of how xanthan gum pasta digests starch. The results indicate that compared to the control group, the concentration of total starch in pasta containing xanthan gum was substantially lower ($70.46 \pm 0.55 \%$) ($p < 0.05$). The reduced starch concentration of 65% in chickpea flour is the reason for this (Osorio - Diaz et al., 2008). Incorporating chickpea flour level increases resistant starch content, as indicated by Osorio-Diaz et al. (2008).

Pasta with xanthan gum added had a greater resistant starch content compared to the control. Considering the favorable effects linked with resistant starch ingestion, it would be irresponsible to dismiss the increased resistant starch content. The dietary fiber content of pasta with xanthan gum added was 13.06 ± 0.08 percent, while the control group had a considerably lower value of 7.91 ± 1.02 percent ($p < 0.05$), according to Mallart et al. (2003). Due to the fact that, according to Osorio-Diaz et al. (2008), both chickpea and buckwheat flour had 19.10% more dietary fiber. As depicted in Table 4.16, the total dietary fiber content of pasta would be considerably affected by their addition ($p < 0.05$). The available carbs were found to be considerably lower ($p < 0.05$) in the xanthan gum pasta group ($48.18 \pm 2.19 \%$) compared to the control group ($59.85 \pm 1.70\%$) when dietary fiber was subtracted from total carbohydrates (Armi et al., 2008).

Due to its physiological benefits in the gut, the dietary fiber in these preparations is crucial. A low postprandial glycemic response may be caused by delayed glucose absorption in diets that include viscous fiber (Bravo et al., 1999; Jenkins et al., 1992). Dietary management for specific people may benefit from xanthan gum pasta's reduced total starch load as a result of enhanced dietary fiber levels. The study was conducted by Osorio-Diaz and colleagues in 2008.

Table 4.16 also indicates significantly ($p < 0.05$) lower glycemic index and glycemic load values of 41.21 ± 1.54 and 24.66 ± 1.16 , respectively. This could be ascribed to higher amounts of resistant starch and dietary fiber and lower levels of available carbohydrates in xanthan gum pasta. The decreased G.I of xanthan gum pasta could

also be ascribed to decrease in starch digestibility or in other words a decrease in available carbohydrates as reported by Rahman (2006). A low G.I diet can be helpful in reducing the risk of developing type -II diabetes, obesity, cardiovascular diseases and some cancers (Garsett et al: 2005., Takao et., 2016). Now days, numerous studies aimed to minimizing the G.I of pasta, bread and bakery products (Brannen and Samyue, 2004; Di Cazrramo et al., 2013). However, in this study, complete replacement of the wheat by buckwheat flour and chickpea flour to make it gluten free diet (Berti et al., 2004) was done. The combined factors of lower starch and available carbohydrates, higher resistant starch content and higher dietary fiber in xanthan gum pasta contributes to its lower glycemic index. Glycemic load and glycemic index are positively correlated to each other (Nayeer et al., 2021) therefore, G.L of xanthan gum pasta (11.96 ± 0.14) significantly ($p < 0.05$) lesser than that of control (24.66 ± 1.16). This ascribes to lower available carbohydrates in xanthan gum pasta than control.

Table 4.16 presents total starch, resistant starch, dietary fibre, available carbohydrates, glycemic index and glycemic load of xanthan gum incorporated extrudates

S. No.	Parameter	Control	Xanthan gum incorporated
1.	Total starch (%)	73.62 ± 0.74^b	70.46 ± 0.55^a
2.	Resistant Starch (%)	2.68 ± 0.18^a	4.27 ± 0.24^b
3.	Dietary fiber (%)	7.91 ± 1.02^a	13.06 ± 0.08^b
4.	Available carbohydrates (Kcal/100g)	59.85 ± 1.7^b	48.18 ± 2.19^a
5.	Glycemic Index	41.21 ± 1.54^b	25.21 ± 0.16^a
6.	Glycemic Load	24.66 ± 1.16^b	11.96 ± 0.14^a

4.2.3.1.4 Cooking Quality characteristics

The features of xanthan gum pasta's cooking quality are displayed in Table 4.17. The processing sector places a premium on cooking quality as it is the most important attribute for customers. According to Hou (2001) and Hymavathi et al. (2019), cooked noodles should have a decent bite, a smooth surface, and a firmness to them. The findings show that the control group required a substantially longer cooking time (4.50 ± 0.24 mts.) compared to the xanthan gum pasta group (4.41 ± 0.23 mts.) ($p < 0.05$). El-Sohaimy et al. (2020) found that xanthan gum pasta's reduced cooking time was due to its increased protein content. This is consistent with the findings published by Padalino et al. (2014) as well. The xanthan gum pasta had a substantially greater water uptake ratio (3.51 ± 0.18) than the control group (3.70 ± 0.13), with a p-value less than 0.05. According to Bhise et al. (2014), this is because chickpea flour is added, which increases the protein levels.

Xanthan gum pasta had a considerably lower solid gruel loss ($5.04 \pm 0.07\%$) compared to the control group (5.23 ± 0.88), which represents the quantity of solids lost to water during cooking ($p < 0.05$). This is because xanthan gum pasta has more protein than regular pasta. Proteins, including gluten, provide a physical network that reduces the solid loss of gruel (Sharma et al., 2018). The solid gruel loss of our product was $5.04 \pm 0.07\%$, which is significantly lower than the 9% figure proposed by AACC (2000) for high-quality pasta. Since a lower solid gruel loss is desirable, our product demonstrates good quality. Xanthan gum pasta (1.09 ± 0.16) showed a substantially larger volume expansion (1.21 ± 0.11) compared to the control group when looking at the findings of volume expansion ($p < 0.05$).

Kaur et al. (2012) also found the same thing with cereal bran enhanced pasta. The volume expansion is further enhanced by the addition of hydrocolloids, such as xanthan gum. The use of xanthan gum enhances their hydrophilicity, which in turn increases their capacity to bind water and, ultimately, their volume (Hymavathi et al., 2019).

Swelling index was observed to be significantly ($p < 0.05$) higher for xanthan gum pasta (22.01 ± 0.35) than control (20.52 ± 0.18). The increased swelling index of xanthan gum

pasta is attributed to enhanced water absorption capacity of chickpea flour owing to its higher protein content (El-Sohaimy et al; 2020, Sorze et al; 2023)

Table 4.17 presents cooking quality characteristics of xanthan gum incorporated pasta

S. No.	Parameter	Control	Xanthan gum –pasta
1.	Cooking time (min)	4.50 ±0.24 ^a	4.41± 0.23 ^a
2.	Water uptake Ratio	3.70 ± 0.13 ^a	3.51 ± 0.18 ^a
3	Solid Gruel Loss	5.23 ± 0.88 ^a	5.04 ± 0.07 ^a
4.	Volume Expansion	1.09 ± 0.07 ^a	1.21 ± 0.11 ^a
5.	Swelling index	20.52 ± 0.18 ^a	22.01 ±0.35 ^b

Values are shown as mean ±standard deviation.

4.2.3.1.5 Sensory evaluation

The results suggest that the overall acceptability of xanthan gum pasta (8.23±0.33) was lower than control (8.31±0.33) although non-significantly ($p>0.05$). The addition of hydrocolloids (xanthan gum) has been observed to significantly ($p<0.05$) affect the sensory scores (Hymavathi et al., 2019) as shown in table 4.18.

Table 4.18 Presents Sensory evaluation (appearance, color, texture, flavour, mouthfeel and overall acceptability) of xanthan gum incorporated extrudates

Parameter	Control	Xanthan gum –Pasta
Appearance	7.30 ± 0.13 ^a	7.16±0.24 ^a
Color	7.39±0.17 ^a	7.26±0.62 ^a
Texture	8.97±0.30 ^a	8.96±0.34 ^a
Flavor	7.80±1.30 ^a	7.63±0.62 ^a
Mouth feel	8.58±0.34 ^a	8.43±0.41 ^a
Overall acceptability	8.31±0.33 ^a	8.23±0.33 ^a

4.2.3.2 Carboxymethyl incorporated extrudates

4.2.3.2.1 Proximate composition

See Table 4.19 for the results of the proximate composition of the C.M.C.-incorporated pasta. C.M.C included pasta had a considerably higher moisture content ($4.78 \pm 0.65\%$) compared to the control ($6.11 \pm 0.86\%$), according to the results ($p < 0.05$). Results for wheat-based pasta added with buckwheat flour were comparable to those reported by Sultan et al. (2020). Similarly, compared to the control, C.M.C pasta had considerably greater amount of crude protein, ash, crude fat, and crude fiber ($p < 0.05$). Sultan et al. (2020) found that when wheat bread pasta is made with buckwheat, these factors go up. The increased levels of protein-rich chickpea flour in the C.M.C integrated extrudates resulted in carbohydrates being considerably ($p < 0.05$) higher in the C.M.C incorporated pasta compared to the control. C.M.C pasta had a considerably greater energy value (319.47 ± 2.26 Kcal/100 g) compared to the control, which had a higher value of 318.47 ± 2.26 Kcal/100 g. The significance level was $p < 0.05$. This is because C.M.C pasta contains more fat and protein than regular pasta. The water activity of the pasta with C.M.C added (0.27 ± 0.02) was lower than that of the control (0.39 ± 0.03), but both samples were much below the range needed for microbial growth, indicating that they were both shelf stable.

Table 4.19 presents the proximate composition of C.M.C incorporated extrudates

S. No.	Parameter	Control extrudates	C.M.C incorporated extrudates
1.	Moisture (%)	6.11 ± 0.86^a	4.78 ± 0.65^a
2.	Crude protein (%)	16.16 ± 0.91^a	16.90 ± 0.19^a
3.	Crude fat (%)	3.03 ± 0.32^a	3.67 ± 0.24^a
4.	Ash (%)	1.12 ± 0.27^a	1.82 ± 0.06^a
5.	Crude fiber (%)	11.82 ± 0.97^a	9.60 ± 0.05^a
6.	Carbohydrates (%)	61.76 ± 1.28^a	63.23 ± 1.26^a
7.	Energy (Kcal/100g)	318.47 ± 2.26^a	319.47 ± 2.26^a
8.	Water activity (a_w)	0.39 ± 0.03^a	0.27 ± 0.02^a

Table 4.20: Summary of Total sugars, reducing sugars and non-reducing sugars in C.M.C incorporated pasta extrudates

S. No.	Parameter	Control	C.M.C
1.	Total sugars	0.07± 0.02 ^a	0.15± 0.01 ^b
2.	Reducing sugars	0.002±0.00 ^a	0.09± 0.05 ^b
3.	Non -Reducing sugars	0.05 ± 0.01 ^a	0.082±0.01 ^b

Sugars, both reducing and non-reducing, and total sugars are given in Table 4.20. Both the control and C.M.C incorporated pasta sugar profiles are shown. Total sugars, reducing and non-reducing sugars values spanning between control and C.M.C pasta were found to be non-significant ($P>0.05$), according to the results.

4.2.3.2.2 Minerals

Table 4.21 presents the mineral content of C.M.C pasta. The mineral content of C.M.C was found significantly ($p<0.05$) high than the control. Calcium, iron, magnesium and zinc were found to be 179.90 ± 4.05 mg/100g, 105.42 ± 1.10 mg/100g, 82.65 ± 0.85 mg/100g and 91.70 ± 0.25 mg/100 g respectively. The significantly ($p<0.05$) high mineral contents of C.M.C pasta could be due to higher ash and thus mineral content of buckwheat and chickpea flour (Sultan et al., 2020). Since, ash and mineral contents are positively similar thus our results corroborate well.

Table 4.21. presents minerals (Calcium, Iron, Magnesium and Zinc)

S.No.	Minerals (mg/100 g)	Control	C.M.C
1.	Calcium	178.62 ±3.21 ^a	187.97±5.03 ^a
2.	Iron	103.28±0.18 ^a	110.48 ±1.30 ^b
3.	Magnesium	80.62±0.36 ^a	85.71±0.93 ^b
4.	Zinc	90.51±0.48 ^a	94.83±0.31 ^b

4.2.3.2.3 Total starch, resistant starch, glycemic index and glycemic load of xanthan gum pasta extrudates.

Here is the starch digestion profile of C.M.C summary of various sugar contents of pasta product as shown in Table 4.22. The results indicate that the total starch of C.M.C. in the pasta was substantially lower ($p<0.05$) at $71.60\% \pm 0.78\%$ compared to the control at $73.62\% \pm 0.85\%$. The reason for this is because chickpea flour has a lower starch content of 65% (Osorio-Diaz et al., 2008). Incorporating chickpea flour level increases resistant starch content, as indicated by Osorio-Diaz et al. (2008).

In comparison to the control, pasta with C.M.C. added had a 4.48 percent greater resistant starch content. Considering the favorable effects linked with resistant starch ingestion, it would be irresponsible to dismiss the increased resistant starch content. In a study done by Mallart et al. (2003), the dietary fiber content of the control group was $7.91 \pm 0.93\%$, which was considerably lower ($p<0.05$) than that of the C.M.C-incorporated pasta group ($14.05 \pm 0.08\%$). Due to the fact that, according to Osorio-Diaz et al. (2008), both chickpea and buckwheat flour had 19.10% more dietary fiber. Thus, as shown in Table 4.22, their addition would have a substantial ($p<0.05$) impact on the dietary fiber content of pasta. The difference of available carbohydrates between the control group ($59.85 \pm 1.49\%$) and the C.M.C group ($51.15 \pm 2.0\%$) was statistically significant ($p<0.05$), since the available carbs were calculated by removing dietary fiber from total carbohydrates (Armi et al., 2008).

Due to its physiological benefits in the gut, the dietary fiber in these preparations is crucial. A low postprandial glycemic response may be caused by delayed glucose absorption in diets that include viscous fiber (Bravo et al., 1999; Jenkins et al., 1992). Some people may benefit from C.M.C. pasta's reduced total starch content as a result of its higher fiber content when it comes to managing their diet. (Osorio-Diaz et al., 2008)

The glycemic index and glycemic load values of 41.21 ± 1.29 and 24.66 ± 1.17 , respectively, are considerably reduced ($p<0.05$) according to Table 4.22. C.M.C pasta may have lower quantities of accessible carbs and higher levels of resistant starch and dietary fiber, which might explain this. According to Rahman (2006), a drop in starch

digestibility, or the amount of carbs that are accessible for use, could explain why C.M.C pasta has a lower G.I. Type II diabetes, obesity, cardiovascular disease, and some malignancies can all be lowered with the use of a low G.I. diet (Garsett et al., 2005; Takao et., 2016). Pasta, bread, and bakery items have recently been the focus of a plethora of research efforts to reduce their G.I. content (Brannen and Samyue, 2004; Di Cazrramo et al., 2013).

However, in this study, complete replacement of wheat by buckwheat flour and chickpea flour was made to make it gluten free diet (Berti et al., 2004). The combined factors of lower starch and available carbohydrates, higher resistant starch content and higher dietary fiber in C.M.C pasta contributes to its lower glycemic index. Glycemic load and glycemic index are positively correlated to each other (Nayeer et al., 2021) therefore, G.L of C.M.C (12.10 ± 0.12) significantly ($p < 0.05$) lesser than that of control (24.66 ± 1.17). This ascribes to lower available carbohydrates in C.M.C pasta than control.

Table 4.22: Total starch, resistant starch, dietary fibre, available carbohydrates, glycemic index and glycemic load in C.M.C incorporated pasta extrudates.

S. No.	Parameter	Control	C.M.C incorporated
1.	Total starch (%)	73.62 ± 0.85^b	71.60 ± 0.78^a
2.	Resistant Starch (%)	2.68 ± 0.12^a	5.21 ± 0.17^b
3.	Dietary fiber (%)	7.91 ± 0.93^a	14.05 ± 0.08^b
4.	Available carbohydrates (Kcal/100g)	59.85 ± 1.49^b	51.15 ± 2.0^a
5.	Glycemic Index	41.21 ± 1.29^b	26.20 ± 0.12^a
6.	Glycemic Load	24.66 ± 1.17^b	12.10 ± 0.12^a

4.2.3.2.4: Cooking Quality characteristics:

Table 4.23 presents the cooking quality characteristics of C.M.C pasta.

S. No.	Parameter	Control	C.M.C incorporated pasta
1.	Cooking time (min)	4.50 ± 0.29^a	5.20 ± 0.20^b
2.	Water uptake Ratio	3.70 ± 0.15^b	2.45 ± 0.15^a
3	Solid Gruel Loss	5.23 ± 1.07^a	5.45 ± 0.02^a
4.	Volume Expansion	1.21 ± 0.14^b	0.09 ± 0.01^a
5.	Swelling index	23.67 ± 0.25^b	19.10 ± 0.25^a

Table 4.23 presents the cooking quality characteristics of C.M.C pasta, which is a crucial factor for consumers and holds significant importance in the processing industry. Ideal cooked noodles should exhibit a firm bite, smooth surface, and pleasant mouthfeel (Hou, 2001; Hymavathi et al., 2019). The data reveal that the control pasta, with a cooking time of 4.50 ± 0.29 mts., had a significantly shorter cooking time compared to C.M.C pasta, which took 5.20 ± 0.20 mts. ($p < 0.05$). The longer cooking time for C.M.C pasta is likely due to its lower protein content, which extends cooking duration (El-Sohaimy et al., 2020). Similar findings were also reported by Padalino et al. (2014).

The water uptake ratio for C.M.C pasta was 2.45 ± 0.15 , significantly lower ($p < 0.05$) than the control's ratio of 3.70 ± 0.15 . This lower water absorption is attributed to reduced protein content (Bhise et al., 2014). The solid gruel loss, which indicates the amount of solids lost to water during cooking, was slightly higher ($p < 0.05$) in C.M.C pasta ($5.45 \pm 0.02\%$) compared to the control ($5.23 \pm 1.07\%$). However, this value is much lower than the 9% threshold suggested by the AACC (2000) for good-quality

pasta, indicating that our product maintains a desirable solid gruel loss. Additionally, C.M.C pasta demonstrated a significantly lower volume expansion (0.09 ± 0.09) compared to the control (1.21 ± 0.14) ($p < 0.05$).

Similar results were also been reported by Kaur et al. (2012) for cereal bran enriched pasta. Addition of hydrocolloids (C.M.C) significantly increases the volume expansion. Addition of C.M.C improves hydrophilicity, thereby increasing their water binding capacity and thus expansion in volume (Hymavathi et al., 2019).

Swelling index was observed to be significantly ($p < 0.05$) high for C.M.C pasta (23.67 ± 0.25) than control (19.10 ± 0.25). The swelling index of C.M.C pasta is attributed to enhanced water absorption capacity of chickpea flour owing to its higher protein content (El-Sohaimy et al. 2020; Sorze et al., 2023)

4.2.3.2.5 Sensory evaluation

The results suggest that the overall acceptability of C.M.C pasta (7.80 ± 0.15) was lower than control (8.31 ± 0.32) although non-significantly ($p > 0.05$). The addition of hydrocolloids (C.M.C) has been observed to significantly ($p < 0.05$) affect the sensory scores (Hymavathi et al., 2019)

Table:4.24 presents Sensory evaluation (appearance, color, texture, flavor, mouthfeel and overall acceptability) of CMC incorporated extrudates

Attributes	Control	C.M.C –Pasta
Appearance	7.30 ± 0.12^b	6.60 ± 0.14^a
Color	7.39 ± 0.16^a	7.10 ± 0.15^a
Texture	8.86 ± 0.22^b	8.0 ± 0.15^a
Flavor	7.80 ± 1.13^a	7.50 ± 0.59^a
Mouth feel	8.58 ± 0.33^b	7.5 ± 0.42^a
Overall acceptability	8.31 ± 0.32^a	7.8 ± 0.21^a

4.4 Storage and packaging evaluations for optimal targeting cold pasta extrudates.

The pasta made from buckwheat and chickpea flour was stored for 90 days, with packaging materials such as low-density polyethylene (LDPE) and aluminum laminate (AL). The pasta samples were evaluated every 30 days for sensory attributes, moisture content, water activity, free fatty acid (FFA) and total plate count (TPC). The results indicated that all assessed characteristics including moisture content, free fatty acids, water activity, sensory attributes, and total plate count was significantly influenced ($p < 0.05$) by both the type of packaging material (LDPE vs. AL) and the duration of storage period.

4.4.1. Moisture content and Water activity

In order to determine how long pasta goods may be stored, two important parameters are their water activity and moisture content. In both the LDPE and AL packaging materials, the impact of moisture content rose significantly ($p < 0.05$) from 5.71% to 7.31% under ambient conditions, and from 5.71% to 6.35% under accelerated conditions. However, in LDPE, the increase was even more pronounced, going from 5.71% to 7.98%, while in AL it was from 5.71% to 7.11%. Pasta, being hygroscopic, can absorb moisture depending on the storage environment and packing material. The effective barrier protection of aluminum laminates resulted in significantly reduced moisture uptake in pasta (Kamble et al., 2020) as shown in Table 4.25.

At ambient circumstances, the water activity in LDPE increased from 0.33 to 0.49 and in AL from 0.33 to 0.40, whereas at accelerated conditions, it increased from 0.33 to 0.45 in LDPE and from 0.33 to 0.47 in AL, as shown in Table 4.26. This increase was statistically significant ($p < 0.05$). Values for water activity taken toward the end of the storage period show that the produced product was protected against microbiological degradation.

Table 4. 25 Variation of moisture content of pasta with storage conditions and packaging materials

Storage period	Ambient		Accelerated	
	LDPE	AL	LDPE	AL
0 day	5.71 ± 1.06 ^a	5.71 ± 1.06 ^a	5.71 ± 1.06 ^a	5.71 ± 1.06 ^a
30 days	6.01 ± 0.1 ^a	5.91 ± 0.06 ^a	6.36 ± 0.03 ^a	6.15 ± 0.05 ^a
60 days	6.93 ± 0.17 ^b	6.12 ± 0.13 ^a	7.06 ± 0.07 ^a	6.91 ± 0.08 ^a
90 days	7.31 ± 0.21 ^b	6.35 ± 0.16 ^a	7.98 ± 0.11 ^b	7.11 ± 0.10 ^a

LDPE: Low Density Polyethylene, **AL-** Aluminium laminates

Table 4.26: Variation of water activity of pasta with storage conditions and packaging materials

Storage period	Ambient		Accelerated	
	LDPE	AL	LDPE	AL
0 day	0.33 ± 0.02 ^a	0.33 ± 0.02 ^a	0.33 ± 0.02 ^a	0.33 ± 0.02 ^a
30 days	0.38 ± 0.01 ^a	0.35 ± 0.02 ^a	0.39 ± 0.02 ^a	0.36 ± 0.05 ^a
60 days	0.41 ± 0.03 ^a	0.38 ± 0.01 ^a	0.43 ± 0.0 ^a	0.41 ± 0.08 ^a
90 days	0.49 ± 0.03 ^a	0.40 ± 0.03 ^a	0.45 ± 0.11 ^a	0.47 ± 0.10 ^a

LDPE: Low Density Polyethylene, **AL-** Aluminium laminates

4.4.2 Free fatty acid

At ambient circumstances, the free fatty acid (FFA) concentration in LDPE pouches increased significantly ($p < 0.05$) from 0.12% to 0.30% while in AL pouches it increased to 0.25%. Under accelerated settings, FFA rose dramatically, rising from 0.12% to 0.34 percent in LDPE pouches and 0.27% in AL pouches (Table 4.27). Storage causes lipid hydrolysis, which leads to an increase in free fatty acid level (Dussert et al., 2006). At the conclusion of the storage period, the FFA values obtained in this investigation fell within the acceptable ranges set by FAO (1981) for processed

goods. Rancidity testing becomes apparent when FFA surpasses 1%, according to Naseer et al. (2021).

Table 4.27 Summary of variation of free fatty acids of pasta with storage conditions and packaging materials

Storage period	Ambient		Accelerated	
	LDPE	AL	LDPE	AL
0 day	0.12 ± 0.17^a	0.12 ± 0.13^a	0.12 ± 0.09^a	0.12 ± 0.12^a
30 days	0.20 ± 0.11^a	0.16 ± 0.09^a	0.23 ± 0.08^a	0.19 ± 0.10^a
60 days	0.240 ± 0.16^a	0.20 ± 0.11^a	0.31 ± 0.09^a	0.22 ± 0.12^a
90 days	0.30 ± 0.19^a	0.25 ± 0.14^a	0.34 ± 0.21^a	0.27 ± 0.17^a

LDPE: Low Density Polyethylene, **AL-** Aluminium laminates

4.4.3. Total plate count

For extrudates kept in LDPE and Al at ambient and accelerated conditions for 120 days, the total plate count was too low to be meaningful (TFTC) (Table 4.28). In contrast, the total plate count for extrudates packed and kept at ambient conditions in LDPE was 0.81×10^1 cfu/g at the 90th day of storage, whereas in AL it was 0.52×10^4 cfu/g. The final count for snacks kept under accelerated settings in LDPE was 0.99×10^1 cfu/g, whereas in AL it was 0.61×10^4 cfu/g. Moreover, the pasta products' TPC levels were within the safe limits of 50,000 as recommended by the Indian standard for high protein extrudates at the conclusion of the storage period (Nagi et al., 2012)

Table 4.28 Variation of total plate count (cfu/g $\times 10^2$) of pasta with storage conditions and packaging materials

Storage period	Ambient		Accelerated	
	LDPE	AL	LDPE	AL
0 day	ND	ND	ND	ND
30 days	ND	ND	ND	ND

60 days	ND	ND	ND	ND
90 days	0.81 ± 0.02^b	0.52 ± 0.01^a	0.99 ± 0.05^b	0.61 ± 0.01^a

ND: Not detected

4.4.4 Effect of storage on sensory evaluation (Overall acceptability) of extrudates.

Table 4.29 shows that there were notable changes in overall acceptability (OAA) during storage for pasta products packed in LDPE and AL, with a p-value less than 0.05. Pasta goods packed in LDPE had an overall accessibility decline of 8.23 to 6.54, whereas developed items packed in AL had an 8.28 to 7.35 drop. It is possible that the color degradation that occurs during storage is responsible for the drop in OAA. Simultaneously, the pasta's crispiness may have diminished due to moisture increase during storage. Pasta may have undergone lipid hydrolysis after 30 days in storage as a result of air permeating the packaging material; this might explain why pasta products with pasta may have had worse taste and mouthfeel ratings (Jalgaonkar et al., 2017). It is possible that a decline in OAA occurred alongside a decline in other sensory qualities that were used to identify them. With an OAA of 7.35 at the conclusion of the storage period, it was clear that the created product maintained a reasonable level of like even after 90 days.

Table 4.29: Variation of overall acceptability of pasta with storage conditions and packaging materials

Storage period	Ambient		Accelerated	
	LDPE	AL	LDPE	AL
0 day	8.23 ± 0.32^a	8.23 ± 0.32^a	8.23 ± 0.32^a	8.23 ± 0.32^a
30 days	8.0 ± 0.26^a	8.13 ± 0.29^a	7.99 ± 0.24^a	8.02 ± 0.17^a
60 days	7.23 ± 0.32^a	7.89 ± 0.28^a	7.01 ± 0.26^a	7.21 ± 0.16^a
90 days	6.54 ± 0.25^a	7.35 ± 0.24^b	6.09 ± 0.26^a	6.21 ± 0.17^a

CHAPTER 5

SUMMARY AND CONCLUSION

The present study targeted a low glycemic pasta extrudates formulation using novel sources such as buckwheat and chickpea. The objectives of the proposed research work were: a) Standardization of various ingredients for the development of cold pasta extrudates using chickpea and buckwheat flour b) Optimization of process conditions for the development of low glycemic chick pea and buckwheat based cold pasta extrudates with xanthan gum and carboxymethyl cellulose c) Storage and packaging evaluations for optimal targeting cold pasta extrudates.

The first objective targeted to develop low glycemic index extruded pasta using buckwheat and chickpea flour by cold extrusion technology. The extruded pasta was prepared with varied concentrations of buckwheat (50-100%) and chickpea (0-50%). The amount of salt and water has been kept constant at 1.5 % and 40% respectively. A trial-and-error approach with six formulations for the varied buckwheat and chickpea flours has been adopted to characterize cooking time, water uptake ratio, solid gruel loss, volume expansion, swelling index, texture, colour and sensory parameters of the developed product. The results affirmed a significant enhancement in water uptake ratio, volume expansion and swelling index from 2.00 -4.23, 0.90 - 1.11% and 18.48-22.67 respectively. On the other hand, cooking time and solid gruel loss have been reduced from 4.28-3.71 min and 8.55-3.74% respectively. Based on such investigations, the optimum characteristics were achieved for T₅ (60:40 buckwheat to chickpea ratio). This investigation provides a guideline for the formation of numerous value-added products with low glycemic index and optimum characteristics.

The second objective involved the formulation of cold extruded pasta using buckwheat, chickpea and xanthan gum/carboxymethylcellulose by applying response surface methodology (RSM). Box Behnken design applied for the optimization of pasta extrudates. The results indicated that buckwheat positively influenced resistant starch content, solid gruel loss, and cooking time, while chickpea had a negative effect on glycemic index. The optimized formulation with 85% buckwheat flour, 35% chickpea

flour, and 3.5% xanthan gum exhibited a lower glycemic index and higher resistant starch content, making it a potentially healthier option for individuals with diabetes or those seeking better dietary choices. Overall, this study demonstrates the potential of utilizing buckwheat and chickpea flours in gluten-free pasta production to improve its nutritional profile, offering healthier options for a growing population with dietary restrictions and health-conscious consumers. The combination of these ingredients with xanthan gum as a binder shows promise for developing innovative and nutritious pasta formulations with broader applications in the food industry. By leveraging the best fit model, the optimization process aimed at maximizing resistant starch while minimizing the glycemic index, glycemic load, cooking time and solid gruel loss using design expert software. The study revealed that the quadratic model provided the most accurate representation for all response variables. Proximate composition of pasta extrudates was also studied and on the basis of desired minimum glycemic index and maximum resistant starch, the xanthan gum incorporated pasta was found to be healthier alternative and contributed dietary choices and overall health.

Third objective was to check the storage and packaging evaluations for optimal targeting cold pasta extrudates. Therefore, the developed pasta extrudates from buckwheat, chickpea and xanthan gum were packed in low-density polypropylene and Aluminium laminate and kept under ambient and accelerated conditions for a storage period of 90 days. All the samples were analyzed for free fatty acids, moisture content, water activity (a_w), sensory analysis and total plate count (TPC) and found that in both the packaging materials effect of moisture content enhanced significantly ($p < 0.05$) from 5.71 % to 7.31 % in LDPE and 5.71 % to 6.35 % in Aluminium laminate. Water activity also showed significant ($p < 0.05$) enhancement from 0.33 to 0.49 in LDPE and 0.33 to 0.47 in AL.

Accordingly, this investigation draws important conclusions as follows: Firstly, incorporation of chickpea flour facilitated to reduce cooking time and solid gruel loss. Also, volume expansion, water uptake ratio and swelling index of pasta extrudates have been enhanced with the increasing or decreasing concentrations of chickpea and buckwheat respectively. Secondly, because of low glycemic index, the developed pasta would positively increase the demand among consumers particularly suffering from

diabetes. This would be beneficial for human consumption as it is highly nutritious, Therefore, it would fix a guideline in the food processing industry to target such value-added products. The combination of buckwheat, chickpea with xanthan gum and carboxymethylcellulose as a binder shows promise for developing innovative and nutritious pasta formulations with greater scope in the food processing sector.

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