EFFECT OF PRE DRYING AND GUAR GUM COATING ON PHYSICO- CHEMICAL, NUTRITIONAL, SENSORY QUALITY AND STORAGE STABILITY OF POTATO CHIPS

by

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Approval Letter

This *dissertation* entitled *Effect of Pre Drying and Guar gum Coating on Physico-chemical, Nutritional, Sensory Quality and Storage Stability of Potato Chips* presented by Raju Bhattarai has been accepted as the partial fulfillment of the requirements for the B.Tech. Degree in Food Technology.

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Abstract

The aim of this study was to evaluate the combined effects of pre-drying and guar gum coating on the physicochemical, nutritional, storage stability, and sensory qualities of potato chips. Fresh potatoes were washed, peeled, and sliced into 1.5 mm thick slices, pre-dried for 30, 60, or 90 minutes at 60ºC at RH approx. 30%, and coated with guar gum at concentrations of 0.25%, 0.5%, 0.75%, and 1%. The coated slices were fried in RBD Palm Olein at 180±5ºc for 3 minutes, drained, cooled, and packaged in polypropylene (PP) material for storage. Proximate analysis of raw potatoes was conducted to establish a nutritional baseline. Sensory evaluation of the chips was carried out using a 9-point hedonic scale, and data were analyzed using two-way ANOVA to determine the effects of pre-drying and coating levels.

The results showed that pre-drying and guar gum coating significantly improved the nutritional profile and reduced oil uptake. The best-performing sample (60 minutes pre-drying with 0.75% guar gum coating) achieved a 44.34% reduction in fat content compared to the control. This sample exhibited enhanced sensory qualities, including superior appearance, texture, taste, and overall acceptability. Proximate analysis revealed higher carbohydrate (61.50%) and fiber (3.81%) content in the sample C. Shelf-life evaluation over 40 days showed gradual increases in moisture content (from 2.801% to 3.610%), peroxide value (from 1.191 meq O_2/kg to 2.379 meq O_2/kg), and acid value (from 0.262 mg KOH/g to 0.428 mg KOH/g). Despite these changes, all parameters remained within safe limits for consumption. These findings confirm that pre-drying and guar gum coating are effective strategies for producing healthier potato chips with improved sensory, nutritional, and storage qualities, offering a healthier and more appealing snack option.

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List of Abbreviations

Abbreviation	Full form
ANOVA	Analysis of variance
AOAC	Association of Analytical Communities
AV	Acid Value
CMC	Carboxymethyl cellulose
DM	Dry Matter
FFA	Free fatty acid
LSD	Least Significant Difference
KMS	Potassium metabisulphite
PP	Polypropylene
PV	Peroxide Value
DFTQC	Department of Food Technology and Quality control

PART I

Introduction

1.1 General introduction

Solanum tuberosum L. (Solanaceae) known as potato is presently the fourth most important staple food crop in the world after maize, wheat, and rice, with a production of 368 million tonnes and play a major role in feeding the world population (Chandrasekara and Josheph Kumar, 2016). Potato tuber develops as an underground stem (swollen part of a subterranean rhizome or stolon) bearing auxillary buds and scars of scale leaves and is rich in starch and storage proteins (Jaspreet Singh and Kaur, 2016). . It is highly nutritious with carbohydrates (22%), proteins (2%), fats (0.1%), water (74%) along with minerals and trace elements viz. potassium, sodium, iodine and magnesium, folic acid, pyridoxine, vitamin C, ascorbic acid and Iron (Sahar *et al.*, 2017). Around the world, this famous vegetable is divided not only by variety and species, but also by colour. Most potatoes are available in different shades of yellow, along with surprisingly blue (purple) and red fleshed varieties used as a natural colorant for food, including healing of wounds caused by burns Kita *et al.* (2013).

The utilization of potatoes throughout the world is moving from fresh to processed potato product such as fries, chips, canned and mashed potatoes and ready meals (Farvin *et al.*, 2012). Potato chips is a type of snacks made of potatoes (*Solanum tuberosum*) by deep fat frying thin potato slices and spiced according to the consumer preference. These are considered as high fat products, as they are reported to contain 35 - 43 g fat per 100 g of chips (Negoita *et al.*, 2020). In industry, the most common frying temperature for potato chips is 180 C (Pedreschi and Moyano, 2005). Apart from the tasty result of potato chips, the high oil content in potato chips as it can absorb about 40% of fat during frying, will increase the exposure of adverse health effect such as obesity, high blood pressure and coronary diseases (Yu *et al.*, 2016).In order to reduce the fat uptake in the potato chips, edible coating effectiveness has been studied to coat the potato chips. Coating deep-fried food with edible coating causes the formation of a protective layer on the surface which can help to diminish the oil uptake in the fried food. These coating materials can be thin and invisible or thick like batter (Varela and Fiszman, 2011) .

The application of the coating is a promising route to reduce the fat uptake in the fried food product. Concerning fat uptake, properties of coating solution are aimed at reducing moisture loss and/or modification of the surface structure form upon frying (M Mellema, 2003)There are several ways to coat food product, such as dipping, spraying and brushing. According to dipping is the most common method used to apply coatings on food materials especially when the coating solution is highly vicious, and the food materials will be dipped into coating solution for 5 to 30 s.

Pre drying is one of the methods of reducing oil uptake in deep fried products. While reducing the food moisture before deep frying was found to effectively reduced the oil uptake during deep frying (J. C. Lumanlan *et al.*, 2020)The oven dryer commonly used in food industry for pre drying effectively reduces moisture content and exhibited improvement in the crispiness and decrease in oil uptake of potato chips (J. C. Lumanlan *et al.*, 2020).Hydrocolloids coatings are chosen for study due to their thermo-gelling properties and as they are invisible. Guar gum, a galactomannan obtained from the Indian cluster bean (Cyamopsis tetragonoloba (L.) Taub), is a water-soluble polysaccharide. The application of a guar gum as a coating agents on the quantity of oil uptake and on sensory attributes of potato is well investigated (Daraei Garmakhany et al., 2008; Daraei Garmakhany et al., 2014; Kim et al., 2011; Pahade & Sakhale, 2012; Yu, Li, Ding, Hang, & Fan, 2016)

In this study, Combination of pre-drying time for 30, 60 and 90 min and guar gum concentrations was investigated in reducing fat content of fried potato chips.

1.2 Statement of Problem

Potatoes are one of the most consumed vegetables worldwide, and potato chips are a popular snack product. However, potato chips face significant challenges in terms of nutritional quality, high oil absorption during frying, and reduced storage stability. Conventional frying methods lead to high-fat content, which poses health risks such as obesity and cardiovascular diseases (Su *et al.*, 2024). Additionally, lipid oxidation during storage results in rancidity, affecting the sensory and nutritional qualities of chips (Adelagun *et al.*, 2023). Addressing these issues requires innovative techniques that balance health benefits, storage stability, and consumer acceptability.

Pre-drying and edible coatings have emerged as promising solutions to these problems. Guar gum, a natural hydrocolloid, is widely recognized for its barrier properties that reduce oil uptake during frying and its ability to retain moisture, extend shelf life, and enhance textural properties (Kolagi *et al.*, 2021). Studies have shown that guar gum coatings can significantly decrease fat absorption by forming a protective layer on the surface of food (Yu *et al.*, 2016). Moreover, guar gum has a positive influence on sensory attributes such as taste, texture, and appearance (S. K. Paramasivam *et al.*, 2022). Despite these potential benefits, there is limited research on how pre-drying and guar gum coatings interact to influence the physicochemical, nutritional, and sensory qualities of potato chips, as well as their storage stability. To address these gaps, this study focuses on evaluating the combined effects of pre-drying time and guar gum coating concentration on the nutritional composition, sensory quality, and storage stability of potato chips. By systematically analysing these factors, this research aims to develop healthier and more shelf-stable potato chips that meet consumer demands while addressing industry challenge

1.3 Objectives

1.3.1 General objectives

The general objective is to study the effect of pre drying and guar gum coating on physico-chemical, nutritional, storage stability and sensory quality of potato chips.

1.3.2 Specific Objectives

The specific objectives of this study will be as follow:

- To determine the effect of pre drying and guar gum coating treatments on the fat absorption of potato chips.
- To understand the influence of pre drying and guar gum coating on the sensory attributes of chips.
- To evaluate the physico- chemical properties of potato chips treated with guar gum coating and pre drying.

1.4 Significance of the study

The significance of this study lies in its potential to address a prevalent health concern associated with the consumption of deep-fried potato chips. Despite their widespread popularity, the high fat content in potato chips contributes to adverse health outcomes such as obesity and cardiovascular diseases. By rigorously investigating the efficacy of guar gum coating and pre drying techniques in reducing fat uptake during the frying process, this research endeavours to offer scientifically grounded solutions for enhancing the nutritional profile of potato chips. The findings of this study could have far-reaching implications for food manufacturers, policymakers, and consumers, providing evidence-based strategies to mitigate the health risks associated with the consumption of deep-fried snack foods. Ultimately, this research aims to contribute to the advancement of food processing technologies and promote public health through improved dietary choices.

1.5 Limitations of the study

The limitations of our study were:

- ✓ Instrumental color and textural analysis were not carried out.
- ✓ Only one packaging materials was used.
- ✓ Shelf life was only studied for 40 days.

PART II

Literature review

2.1 Potato

Potato is in the fourth order in terms of production and area harvested, behind maize, wheat, and rice, as a staple crop for human nourishment, with an output of over 368 million tonnes. Potato is in the fourth order in terms of production and area harvested, behind maize, wheat, and rice, as a staple crop for human nourishment, with an output of over 368 million tonnes. (Angor *et al.*, 2013). This famous tuber is grown in 80 percent of the world's countries (Gnanasekaran and Basalingappa, 2018). Potatoes can produce more nutritious food on less area and under tougher conditions than most other important crops. Furthermore, this tuber can be harvested after just 8 weeks (Nzaramba *et al.*, 2007). Solanum tuberosum is a versatile, carbohydrate-rich meal that is eaten and cooked in a number of ways all over the world. This tuber is often viewed as a ritual dish or a garnish for other major meal components, and it is used as a supplementary vegetable to basic foods (Navarre *et al.*, 2009).

Solanum tuberosum is a rich source of various biochemical and nutritional properties, such as ascorbic acid, reducing and non-reducing sugars, total sugars, phenolic content, flavonoids, polyamines, and carotenoids, all of which are beneficial to human health and are therefore highly desirable in diets (Mishra *et al.*, 2020).

2.2 Historical Background of potato

The potato, or Solanum tuberosum, was first domesticated more than 7,000 years ago in the Andean area of South America, mostly in what is now northwest Bolivia and southern Peru. Native American communities residing in these areas cultivated and selectively bred wild potato species, resulting in the creation of many strains that could flourish in a range of climates and altitudes (Hawkes and Francisco-Ortega, 1992).

Following the Spanish conquest of the Inca Empire, Spanish explorers introduced the potato to Europe in the late 16th century. Initially, European societies were sceptical and hesitant to adopt the new crop, partly due to unfamiliarity and mistrust of its appearance and cultivation methods (McNeill, 1999). However, over time, the potato gained acceptance, particularly in Ireland and the British Isles, where it became a crucial food source due to its high yield and nutritional content. This acceptance was driven by the demands of the Agricultural Revolution, which required reliable and nutritious crops to support growing populations (Salaman and Burton, 1985).

By the 18th century, the potato had spread across Europe and into Asia and Africa, becoming a critical component of agricultural systems worldwide. In Prussia, Frederick the Great promoted the cultivation of potatoes to combat hunger, while in Russia, Catherine the Great endorsed its farming to enhance agricultural productivity and support population growth (Zuckerman, 1999). In Ireland, the potato's centrality to the diet meant that the crop's failure due to the blight Phytophthora infestans in the mid-19th century led to the Great Irish Famine, causing widespread starvation and mass emigration (Hijmans, 2003). In the 20th and 21st centuries, advances in agricultural technology and breeding programs have produced disease-resistant and climate-resilient potato varieties, ensuring its continued prominence in global agriculture (Hijmans, 2003).

The potato is increasingly valued for its potential to combat nutritional deficiencies, especially in developing countries. It is rich in essential vitamin, minerals, and antioxidants, making it a crucial dietary component in areas where malnutrition is a concern (CIP, 2020). The International Potato Center (CIP) continues to drive research and development efforts to improve potato varieties and promote sustainable farming practices globally, underscoring the ongoing significance of this versatile crop.

2.3 Taxonomy

The potato is a dicot plant belonging to family solanaceae and the genus Solanum. This is a largest genus of angiosperms and comprises nearly 90 genera and 2800 species. Genus Solanum has been divided into two sub genuses namely Pachystemonum and Leptostemonum as per the latest classification. Pachystemonum has been further divided in to five sections of which section Petota, contains most of the tuber bearing species. Section petota has been divided under two subsections, namely Estolonifera and potatoe. All cultivated species grouped under the series Tuberosa of subsection potato (Thamburaj and Narendra, 2016). About 72 % of the species are diploid (2n=24) and nearly 12% tetraploid

(2n=48). The rest are triploid (2n=36), pentaploid (2n=60) and hexaploid (2n=72). The widely cultivated potato belongs to tetraploid species

Scientific classification

Kingdom:	Plantae
Sub kingdom:	Viridaeplantae
Division:	Magnoliophyta
Class:	Magnoliopsida
Subclass:	Asteridae
Order:	Solanales
Family:	Solanaceae
Genus:	Solanum
Species:	*Solanum tuberosum L*

Source: Ovchinnikova *et al.* (2011)

2.4 Morphology

The potato (*Solanum tuberosum*), a member of the Solanaceae family, is a vital agricultural crop known for its nutritional value and versatility in culinary applications. As an herbaceous plant, it exhibits a range of morphological features that contribute to its adaptability and growth. The study of its morphology encompasses the examination of various structures, including the tubers, stems, leaves, roots, seeds, and flowers. Each of these components plays a crucial role in the plant's life cycle and overall function.

2.4.1 Habit:

The potato (*Solanum tuberosum*) is an herbaceous plant characterized by a growth habit that varies among species. It typically exhibits rosette or semi-rosette characteristics and can be classified as annual, biennial, or perennial depending on the variety(Das *et al.*, 2021).

2.4.2 Tuber:

Potato is an annual non-woody (herbaceous) plant, mainly reproduced vegetatively via tubers and typically by botanical seeds, i.e., True Potato seeds. The Potato tuber is an enlarged part of an underground stem from which new shoots are produced. The Tuber is morphologically a fleshy stem, carrying buds and eyes in the axil of small scale like leaves(de los Angeles Bohórquez-Quintero *et al.*, 2022). Eyes are concerted near the apical end of the tuber, with small number near the stolon or basal end. Eye number and distribution are characteristics of the variety

2.4.3 Stem:

Initially, the stem of the potato plant is erect, but as it matures, it becomes proliferate and prostrate, extending horizontally.

2.4.4 Leaves:

The leaves are alternate and compound, typically arranged in an asymmetrically odd pinnate formation with 6-8 pairs of leaflets. Each petiole measures between 2.5-5 cm in length and the leaflets vary in size from 1-6 cm to 2-10 cm, exhibiting a dark green color. The leaves terminate in a residual pinnate structure and are often sparsely pilose (hairy). Buds formed in the axils of the leaves can develop into rhizomes that extend rapidly to form tubers at their ends (Das *et al.*, 2021).

2.4.5 Roots:

Potato plants have a fibrous or tuberous tap root system, which supports their growth and nutrient uptake from the soil.

2.4.6 Seed:

The seeds of the potato are classified as endospermic seeds, which contain stored food to nourish the developing plant embryo.

2.4.7 Flower:

Potato flowers exhibit two types of pollination: self-pollination and cross-pollination, facilitated by insects, bees, and birds. The flowers typically have five petals that can be white, lavender, or purple (Angmo *et al.*, 2024).

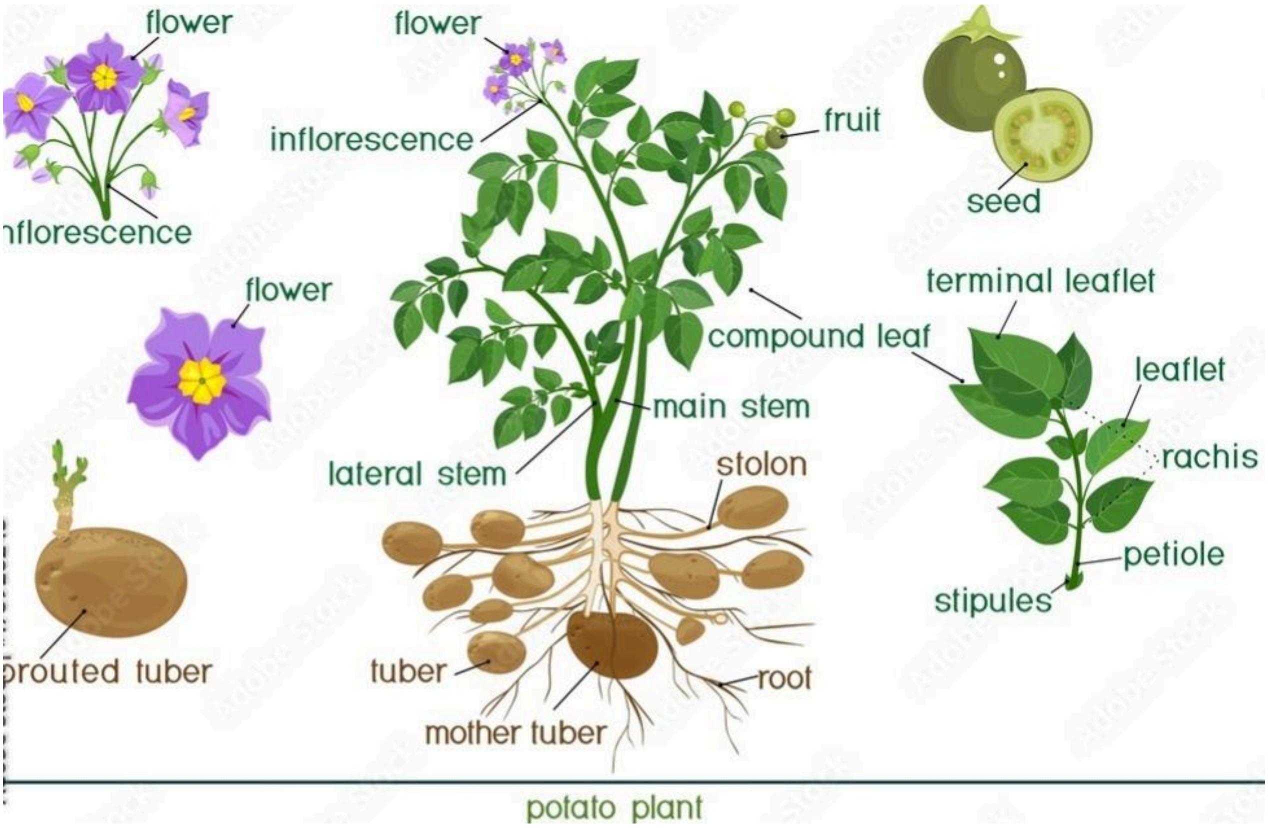

Fig.2.1 Morphology of potato

Source: Das *et al.* (2021)

2.5 Nutritional composition of potato

Potato has been discovered to be a highly nutritious vegetable. Potato tubers that have just been harvested have about 80% water and 20% dry matter. Although the main ingredient of

Potato is starch, it also contains trace levels of protein and alkaline salts. These are sugars that are nearly fat- and cholesterol-free complex carbohydrates. Potato contains a variety of vitamin, including beta-carotene, vitamin C, A, B1, B2, B6, and folic acid. Additionally, it has trace amount of nicotinic acid, protein, and amino acids (Navarre *et al.*, 2009). However, there have been considerable differences. Many of the nutrients in Potato are located in their skin, therefore eating them whole rather than peeled has been linked to increased health advantages (Brar *et al.*, 2017). *Potato* is not only important food security crops, but they are also excellent candidates for commercial use (Farvin *et al.*, 2012). Processing add value to this tuber, increases shelf life and convenience, lowers post-harvest losses and waste, and produces a varied range of products for a variety of uses. Potato tubers can be consumed fresh or processed into products like French fries, crisps, and canned potatoes (Hussain, 2016). In addition to supplying energy, potatoes contain a number of health promoting antioxidants such as phenolics, flavonoids, folates, anthocyanins, and carotenoids and biochemical such as starch content, dry matter, ascorbic acid, reducing sugars, non-reducing sugars and total sugar.

Table 2.1: Nutritional composition of Solanum tuberosum

Nutrients	Amount (per 100 g)
Water	79.25 g
Energy	77 kcal
Protein	2.05 g
Total fat	0.09 g
Dietary fiber	2.1 g
Carbohydrate	17.49 g
Calcium	12 mg
Iron	0.81 mg
Magnesium	23 mg
Phosphorus	57 mg
Potassium	425 mg
Sodium	6 mg
Manganese	0.153 mg
Vitamin C	19.7 mg

Source: Khalid *et al.* (2020)

2.6 Potato chips

Potato chips is a type of snacks made of potatoes (*Solanum tuberosum*) by deep fat frying thin potato slices and spiced according to the consumer preference. Their production process consists of several critical steps: selecting high-quality potatoes, washing, peeling, slicing into thin rounds, frying in oil, and seasoning.

These are considered as high fat products, as they are reported to contain 35 - 43 g fat per 100 g of chips (Negoita *et al.*, 2020). In industry, the most common frying temperature for potato chips is 180 C (Pedreschi and Moyano, 2005) Apart from the tasty result of potato chips, the high oil content in potato chips as it can absorb about 30% of fat during frying, will increase the exposure of adverse health effect such as obesity, high blood pressure and coronary diseases (Yu *et al.*, 2016).

In order to reduce the fat uptake in the potato chips, edible coating effectiveness has been studied to coat the potato chips. Coating deep-fried food with edible coating causes the formation of a protective layer on the surface which can help to diminish the oil uptake in the fried food. These coating materials can be thin and invisible or thick like batter (Varela and Fiszman, 2011).

The application of the coating is a promising route to reduce the fat uptake in the fried food product. Concerning fat uptake, properties of coating solution are aimed at reducing moisture loss and/or modification of the surface structure form upon frying (M Mellema, 2003b). There are several ways to coat food product, such as dipping, spraying and brushing. According to dipping is the most common method used to apply coatings on food materials especially when the coating solution is highly vicious, and the food materials will be dipped into coating solution for 30-60 seconds.

2.7 History and origin of potato chips

Potato chips are deep-fried, thinly sliced potatoes, with a finished moisture concentration of 1.3–1.5%. They are fried in different types of vegetable oil, with a range of added flavours. Potato chips have a US origin dating back to 1853 in a hotel kitchen at Saratoga Springs, New York. The first commercial production got underway in 1895 (W. J. I. T. M. Gould, 1999). According to Gould, eleven new chip plants started production during 1895–1928, giving rise to a number of familiar brands that are still in the market in 2005. In the UK, Smith’s Crisps began production in 1920. Several innovations mark the industry’s subsequent development.

During the 1920s, Herman Lay developed the mechanical potato peeler, which stimulated production for a mass market. About the same time, Laura Scudder pioneered the packaging of potato chips in sealed bags, initially made from waxed paper, later from cellophane. Seasoning technology was developed in the 1950s by the owner of 'Tayto' in Ireland. This allowed controlled amounts of salt and a range of natural and artificial flavours to be added automatically. In recent years, microprocessor-controlled weighing heads (1985), optical sorting to remove defective product (1990), and nitrogen-fill to preserve freshness (1995) have contributed to state-of-the-art potato chip manufacture (Kirkman, 2007).

Potato chips have evolved significantly in terms of flavour and style. Chips have evolved to meet local tastes around the world, from simple salted chips to exotic flavours like barbecue, sour cream, and onion, as well as international varieties. The snack industry has also been shifting toward healthier options. As consumers seek healthier alternatives, baked chips, chips made from other vegetables, and low-sodium versions have become increasingly popular (Burhans, 2008).

2.8 Production of potato chips

Potato chips, a popular snack, play a key role in the worldwide snack food business. Their manufacturing entails multiple meticulous phases, including the selection of raw ingredients, peeling, slicing, pre-treating the slices to prevent browning, frying, seasoning, and packing, each of which strongly influences the quality and acceptance of the final product.

2.8.1 Selection of raw ingredients

High-quality potatoes with high starch content and low sugar content are selected to ensure crispiness and reduce browning during frying.

2.8.2 Cleaning and Peeling

Cleaning:

Potatoes are washed thoroughly to remove dirt, stones, and other foreign materials.

Peeling:

Potatoes are peeled using mechanical, abrasion peelers, caustic peeling or hand peeler to remove the skin.

2.8.3 Slicing:

Without doubt this is the most important operation in a chip plant. With efficient slicing procedure clean slices without any feathered edges are prepared which adsorb less oil and do not leave potato pieces in the oil to cause it to break down more quickly. After peeling slicing is done by stainless steel knife, mechanical slicer in varying thickness.

2.8.4 Washing of potato slices

There are two schools of thought in terms of washing after slicing. Some argue that the slices should not be washed, while others place a high value on this process. W. A. Gould (1999) suggests that the slices should be washed to be free of loose starch before entering the fryer to prevent oil breakdown and dark specks on the chips.

2.8.5 Blanching

Blanching as a pre-treatment greatly reduces acrylamide production in potato pieces after frying. Not only did the glucose and asparagine content fall dramatically as the temperature and time of blanching increased, resulting in potato chips with reduced acrylamide after frying. Long-term blanching treatments at 50ºC for 80 min and 70ºC for 45 min resulted in the lowest acrylamide production (J. Singh and Kaur, 2009).

2.8.6 Surface drying

Excess moisture is removed from the slices using air dryers or centrifugal dryers. This step ensures that the slices fry evenly and become crispy. Texture has been recognized as one of the most important quality attributes in dried potatoes which contribute to the consumer acceptance. Texture of potatoes is affected by drying processes and it is strongly associated with composition and structure of cell walls (Ramos *et al.*, 2003)

2.8.7 Frying

There are two fundamental methods for frying potato chips: batch or continuous. The batch process is used to make potato chips labelled as 'home style', 'old fashioned', or 'kettle style'. The chips in the batch process are solid and have a terrific bite. The batch system takes longer, up to 8 to 10 minutes per batch, although the temperature is often lower, and the oil concentration may be slightly higher. Most manufacturers employ the continuous system with vastly varying heating systems; some use direct firing while others use side heat exchangers (W. A. Gould, 1999).

2.9 Physicochemical Properties of Potato Chips

Potato chips are a popular snack item with distinct physicochemical qualities that affect their quality, acceptability, and shelf life. These qualities include moisture content, oil content, texture, color, ash content, and pH, among others. Each attribute contributes significantly to the product's sensory appeal, nutritional value, and storage stability (Pinhero *et al.*, 2012). Moisture content has a direct impact on potato chips crispness and microbiological durability, whereas oil concentration influences their caloric value and flavour (Kaur *et al.*, 2008). The texture, assessed as hardness, is an important factor impacting consumer pleasure. PH and water activity (aw) indicate the product's chemical stability and microbial safety during storage. Processing procedures such as pre-drying and coating with guar gum can have a substantial impact on the physicochemical qualities of potato chips. These techniques can reduce oil uptake, improve textural qualities, and extend shelf life (Cruz *et al.*, 2018). Physicochemical Properties of potato chips is shown in table 2.2.

Table 2.2 Physicochemical properties of potato chips

Parameter	Value range
Moisture content	1.2-2.8%
Oil content	30-40%
Protein content	6.2-8.1%
Ash content	1.1-1.9%
Carbohydrate	55-60%
pH	5.8-6.3
Peroxide value	4.5-9.5 meqO2/kg

Source : Cui *et al.* (2024)

2.10 Oil used in frying

The mostly used oil for frying is soybean, sunflower oil and palm oil.

2.10.1 Soybean oil

The soybean (*Glycine max*) is a legume native to East Asia, widely grown for its edible bean. Soyabean is used in many ways, like for food preparation like kinema or tofu or used as oils. Soybean is one of the dominant oilseeds used in the world, because of its favourable agronomic characteristics, high-quality protein, and valuable edible oil. They are used for cooking, frying, spreads, and shortening (F. Gunstone, 2011).

Soybean oil is recovered by solvent extraction or mechanical pressing. Crude oil contains primarily neutral lipids including tri-, di-, and mono-acylglycerols, free fatty acids, and phospholipids. It also contains a minor amount of phytosterols, tocopherols, and hydrocarbons. Trace metals are also found in soybean oil in concentration of ppm which reduces during refining (F. Gunstone, 2011). Refined, bleached, and deodorized (RBD) soybean oil is used for commercial frying, which were hydrogenated to increase stability during commercial frying and storage of fried food. However, nonhydrogenated oils are now popular alternatives to hydrogenated oils as reducing the amount of linolenic acid significantly increases the oxidative stability of soybean oils (Warner, 2008). The DFTQC Nepal standard of soybean oil shown in the Table 2.3.

Table 2.3: DFTQC Nepal Standard of soybean oil

Parameters	Value
Acid value (mg of KOH/g of oil)	< 2.5
Peroxide value (meqv O_2/kg of oil)	< 10
Iodine value	120-140

Source: (DFTQC, 2022)

2.10.2 Sunflower oil

Sunflower (*Helianthus annuus L.*) belongs to the family Compositae. They are composed of triacylglycerols (98–99%) and small proportion of phospholipids. Unsaponifiable matter present contains tocopherols, sterols and waxes along with other substances. Fatty acid composition of sunflower oil is given in Table 2.3. Due to its relatively good oxidative stability, refined sunflower oil has been used both for domestic and industrial uses. However, the oxidative stability of vegetable oil depends not only on the amount of natural antioxidants remaining in the oil after refining, but also depends on the added antioxidants and quality parameters of the refining process (F. Gunstone, 2011).

In countries where sunflower oil is common edible oil, it is used as salad dressing, cooking and frying oil. Sunflower oil rarely reaches the critical value of polar compounds during continuous frying processes, but results are bad for discontinuous uses. When stored in dark, soybean oil has a higher oxidative stability than regular sunflower oil, despite soybean oil content of linolenic acid. However, when stored in the light, oxidative stability of sunflower oil is higher than that of soybean oil (F. Gunstone, 2011). The DFTQC Nepal standard of sunflower oil shown in the Table 2.4.

Table 2.4: DFTQC Nepal Standard of Sunflower oil

Parameters	Value
Acid value (mg of KOH/g of oil)	< 4
Peroxide value (meqv O_2/kg of oil)	< 10
Iodine value	110-143

Source: (DFTQC, 2022)

2.10.3 Palm oil

Palm oil is extracted from the fleshy orange red mesocarp of the fruit of the oil palm (*Elaeis guineensis*). This plant, indigenous to West Africa, has spread to the tropical and subtropical zones of the world, particularly Malaysia and Indonesia (Edem, 2002). It is extracted in the oil mill and then fractionated, bleached and deodorized in the refinery (Pimpa *et al.*, 2009). It is a highly viscous semi-solid fat, orange red in colour and has 45- 56 iodine value and 31.38°C melting point. Palm oil, melting in the range 21–27°C, can be fractionated to give solid (palm stearin, 30–35%, mp 48–50°C) and liquid fractions (palm olein, 65–70%, mp 18– 20°C), thereby extending the range of usefulness of this oil.

Palm olein is a high-quality, highly stable frying oil. Palm stearin is the less valuable commodity, but it can be used as a hard fat in the production of spreads and as a vegetable alternative to tallow in the oleo- chemical industry (Khetarpaul *et al.*, 2007). Palm oil consists mainly of glycerides (9%) and about 0.5 per cent non-glyceride materials. The nonglyceride components include free fatty acids (FFA), trace metals, moisture, impurities, and minor components. Crude palm oil contains approximately 1% minor components, which include carotenoids, vitamin E, sterols, phospholipids, glycolipids, terpene, and aliphatic hydrocarbons. The carotenoids, tocopherols and tocotrienols are the most important of these minor components. They contribute to the stability and nutritional properties of palm oil (Liu *et al.*, 2008). The oil contains almost equal proportions of saturated (palmitic 48% and stearic 4%) and unsaturated acids (oleic 37% and linoleic 10%) (WU and Ng, 2007). Palm oil contains 5% of diacylglycerols and low phospholipids (5–130 ppm) (Frank Gunstone, 2009).

Table 2.5 Fatty acid composition of palm oil and its fractions

Oil Source	16:0 Palmitic	18:0 Stearic	18:1 Oleic	18:2 Linoleic
Palm Oil	44	4	39	11
Palm Olein	41	4	41	12
Palm stearin	47-74	4-6	16-37	3-10

Source: Khetarpaul *et al.* (2007)

Palm oil is potentially one of the best sources of vitamin E. The vitamin E content in palm oil is unique in that it is composed of tocotrienols rather than tocopherols. Palm oil normally contains 600–1,000 mg/L, of which 43% is γ-tocotrienol, 24% is α-tocotrienol, 11% is δ-tocotrienol, and 21% is α-tocopherol. Tocopherols and tocotrienols are potent natural antioxidants that play an important role in the stabilization of oils and fats. They extend the induction period and delay the time when oxidation produces off-flavors and/or odors (Edem, 2002). Palm tocotrienols may also have beneficial health impacts as they have been reported to lower plasma cholesterol by inhibiting the activity of HMG-CoA reductase, which regulates cholesterol synthesis in the liver. Tocotrienols may also play an important role in suppressing the progression of certain types of cancer particularly breast cancer (Liu *et al.*, 2008). Recent studies have shown that palm oil and/or its antioxidant constituents are effective in controlling arthrosclerosis and certain types of cancer. Tocotrienols, which are active components of palm oil, are shown to be effective in preventing oxidative damage to lipids in vitro and in vivo.

The advantages of the palm oil are not only economic. The high content in monounsaturated acids drop rates of LDL – "bad "cholesterol – all while maintaining the

HDL or “good " cholesterol. The uniqueness of palm oil from other vegetable oils lies in its fatty acid composition and their position in the triglyceride structure. Inspite of its higher palmitic acid content, red palm oil does not behave like animal fats that are rich in saturated fatty acids. This is because, in palm oil the middle (2nd) position of triglyceride structure is occupied mainly by unsaturated fatty acid (oleic), which are absorbed into the intestine after the fatty acid at 1 and 3 positions are split off during digestion. Thus, more of oleic acid is available to the body from palm oil. It could be blended with other 34 vegetable oils rich in polyunsaturated fatty acids such as sunflower, groundnut, coconut etc. so that crude palm oil blend contains recommended ideal fatty acid composition which is required for the maintenance of good health (Khetarpaul *et al.*, 2007)

Palm oil also has balanced fatty acid content with equal ratio of saturated to unsaturated fatty acids. The presence of natural antioxidants, tocopherol and tocotrienol further contribute to the superior oxidative stability of palm oil. Unlike the unstable polyunsaturated edible oils, palm oil does not have to be hydrogenated to impart stability. Hence, it is naturally free of trans fatty acid. Another important attributes of palm oil, which help to distinct it from others, is its bland taste. This helps to carry the natural flavor of the food during frying process (Mahat, 2012). Palm olein (IV 56–59) is used mainly as frying oil, palm stearin (IV 40–42) as hard stock, and palm mid-fraction (range of iodine values between 32 and 47) in confectionery fat (Frank Gunstone, 2009).

Table 2.6: DFTQC Nepal Standard of palm oil and palm olein

Parameters	Palm oil	palm olein
Acid value (mg of KOH/g of oil)	< 6	< 6
Peroxide value (meqv O_2/kg of oil)	< 10	< 10
Iodine value	45-56	54-62

Source: DFTQC (2022)

2.11 Mechanism of oil uptake during deep frying and cooling

Understanding the mechanism of oil uptake during deep-frying will facilitate the food industries into optimising the solutions in reducing the fat content while retaining the favourable characteristics of fried foods at a considerable cost (Lumanlan *et al.*, 2020). The elements influencing the oil uptake during the process are as follows:

2.11.1 Deep frying

Deep fat frying is a conventional frying method for chips production, basically it includes the immersion of potato slices in a vegetable oil at temperature of around 120-200°C that causes drying by means of frying. The high temperature causes an evaporation of the water, which moves away from food and through the surrounding oil. Oil is absorbed by food, replacing some of lost water (Suyatma *et al.*, 2015)

Deep-fat frying involves heating food in edible oil at temperatures higher than the boiling point of water, which can be classed as a dehydration process (Farkas, 1994). This method is one of the oldest and most commonly utilized unit operations in food preparation. Deep-fat frying is a popular method for processed meals due to its distinct flavor and texture. During frying, heat transfer causes protein denaturisation, starch gelatinization, water evaporation, crust formation and colour development. Mass transfer is characterized 6 by water and some soluble material escaping from the product during the process, combined with oil penetrating the food (Mir-Bel *et al.*, 2009). Lumanlan et al. (2019) reported that more water loss during deep-frying resulted in more oil absorption. For example, higher temperature, rapids the development of thicker crust resulted in the reduction of moisture content and oil uptake. While lower temperature requiring longer frying time resulted in higher fat content. It was concluded that continuous deep-frying leads to more water loss and formation of thicker crust favourable to oil absorption (B Baumann *et al.*, 1995).

2.11.2 Oil uptake

Oil uptake is a complex process which involves numerous physical, chemical and structural transformations during frying. The surface phenomenon is an equilibrium between adhesion and drainage with the most significant part of the fat absorption is at the end of the frying period (Ufheil and Escher, 1996). During cooling, the competition between oil outflow and the suction within the crust results in higher fat content in potato chips (Moreno *et al.*, 2010). For example, the crust of the french fries contains about six times as much oil as the inner part (Aguilera and Gloria, 1997), while Keller *et al.* (1986) showed that the frying oil remained on the porous surface region of the french fries. This was further confirmed with the electron scanning microscope that oil was mainly located in the surface of potatoes (Lisinska and Golubowska, 2005).

2.11.3 Heat and mass transfer

During deep frying, heat and mass transmission occur concurrently. Mass transfer occurs when water is lost from the interior to the outside and replaced with surface oil while immersed in heated oil. The heat transmission between oil and product was regulated during frying (Ziaiifar *et al.*, 2008). The heating medium, frying oil, accounts for up to 40% of the overall mass, with the majority of lipids found in the crust of the finished product, such as chips. The oil does not permeate the microstructure but enters the voids during cell breakdown when water is removed from the product. Most oils are absorbed after food is removed from deep fryers (Varela and Fiszman, 2011; Ziaiifar *et al.*, 2008). Furthermore, the development of the thicker crust from the rapid moisture evaporation during deep frying limits the oil migration into the inner structure while increases the oil uptake during the cooling period (Cortés *et al.*, 2014)

2.11.4 Oil uptake during deep frying and cooling

During deep frying, the water loss led to moisture evaporation expands the capillary pores resulting in oil adhering on the surface of the food. Limited oil is absorbed during this process, while the steam is escaping when food is immersed in the hot oil. However, after food is removed from the deep fryer, the oil penetrates the microstructure by vacuum forces created by evaporative cooling (Durán *et al.*, 2007). Indeed, the oil absorption is slower during frying period, however, most oil fill-up the porous crust during the cooling time (J. C. Lumanlan *et al.*, 2020). According to A. Garmakhany *et al.* (2008), about 20% oil uptake takes place during deep frying and about 80% during cooling. They stated that the rapid release of water vapour limits oil absorption into the porous crust developed during deep frying, and more oil was absorbed during cooling.

2.12 Factors affecting oil uptake

Factors affecting the oil uptake during deep frying contribute to the fat content. The factors affecting oil uptake are:

2.12.1 Porosity

The rapid and continuous water evaporation during deep frying resulted in structural changes such as, surface dehydration and development of porous structure (B. Baumann and Escher, 1995) have attributed to the improvement of the crispy and crunchy texture of the potato chips, consequently resulting in increase in fat content. For example, the development of the crust in French fries was found nearly six times more porous than the core indicating its capacity for oil absorption (J. C. Lumanlan *et al.*, 2020).

During deep frying, the moisture is converted into steam and escapes through the microstructure, damages the cells and expands the pores forming tunnels of capillaries. The vigorous release of water vapour, creating a barrier, could prevent oil migration into the porous crust and limits oil absorption during frying. Nevertheless, after the food was removed from the hot oil, a condensation of water vapour in the porous crust creates a 'vacuum effect' absorbing more oil (J. C. Lumanlan *et al.*, 2020).

2.12.2 Surface area and roughness

The dimension and structural properties influencing the oil uptake during deep frying are not linked to the volume, but to the permeability and the surface area of the product, and the increase in fat content are due to most oil adhered on the food surface (J. C. Lumanlan *et al.*, 2020). More recently, Ghaderi *et al.* (2018) showed that simulated potato strips with increasing surface area to volume ratio of potato strips affect the moisture and oil content. For example, increasing the thickness of potato slices from 0.8 to 1.2 mm resulted in a significant increase in fat content due to thicker food requiring longer frying time (Lumanlan *et al.*, 2020). On the other hand, Moreno *et al.* (2010) found that mixing 10% methyl cellulose with 90% potato flakes decreased the surface roughness and reduced the fat content after deep frying. B. Baumann and Escher (1995) pointed out that surface coarseness facilitates oil absorption and adhesion. Therefore, using sharper blades for cutting will have a smooth surface and could result in lower oil uptake during deep frying.

2.12.3 Frying time and temperature

Frying time and temperature are the most important parameters influencing chemical and physical transformation such as water loss, fat content and final product quality. Ghaderi *et al.* (2018) confirmed that increasing the temperature from 150 to 190 °C decreased the fat content by up to 35% by using a 3- D mathematical model to simulate a domestic deep fryer. Also, Krokida *et al.* (2000) stated that increasing the frying temperature and time decreases moisture content and an increase in oil content. They explained that food with lower thickness may contain more oil due to the water loss and oil uptake getting more intense at higher temperature with shorter frying time. Lower temperature (e.g., 150 °C) requiring longer frying time results in higher oil uptake, and higher temperature (e.g., 180 °C) leading to the rapid development of harder crust in shorter time results in lower oil uptake (B. Baumann and Escher, 1995). It was concluded that the development of crust where most oil is deposited is associated with frying time and temperature (Lumanlan *et al.*, 2020)

2.12.4 Fresh oil and degraded oil

Extended frying time and higher temperature leading to autoxidation, thermal oxidation and polymerization are associated with oil degradation. A recent study shows that the degraded oil with higher oil viscosity can affect amount of oil uptake during deep frying and cooling period. Also, the unsaturated fatty acids showed an increase in free radicals and decreased in oleic and linoleic acid resulting in oil degradation with increasing frying time (J. C. Lumanlan *et al.*, 2020). Pinthus and Sam (1994) found that oil exposed to 10 h frying at 170 °C resulted in higher fat content in the final product compared to frying in fresh oil.

2.12.5 Moisture content

Moisture content influences the quality of fried dishes that people enjoy. After deep frying, food with little moisture content, such as chips, can shrink by up to 40% due to crust formation and surface bubbles (Sahin, 2009). Durán *et al.* (2007) reported that the crust on the food surface adds texture, colour, and flavour, while the core holds the majority of the mass, moisture, and nutrients. Deep frying at 180°C reduced moisture content of potato slices (3 mm) from around 80% to 2%. Ziaiifar *et al.* (2008) observed that deep frying at high temperatures (170-185 °C) decreased moisture compared to lower temperatures (140-150 °C).

2.13 Methods in reducing oil uptake during deep frying

Reducing oil consumption during deep-frying can benefit both the food industry and customers. Researchers are interested in producing high-quality, low-fat fried foods at a reasonable cost. Low-fat foods may help prevent obesity and the negative impact of excessive oil consumption on consumers' health and wellbeing (Lumanlan *et al.*, 2020).

2.13.1 Pre- drying

During deep frying, oil replaces the water that was evaporated. While reducing the food moisture before deep frying was found to effectively reduced the oil uptake during deep frying (J. C. Lumanlan *et al.*, 2020). Recently, Dehghannya and Abedpour (2018) investigated the ultrasound osmotic dehydration in reducing potato strips moisture before deep frying and found a significant influence in moisture loss and decreasing fat content. However, the cost to process low-fat chips using the method developed by the researchers is not economical for commercial production. Alternatively, the oven dryer commonly used in food industry for pre drying effectively reduces moisture content and exhibited improvement in the crispiness and decrease in oil uptake of potato chips (J. C. Lumanlan *et al.*, 2020). In addition, (Kumar *et al.*, 2017) reported that reducing moisture content of taro slices after oven drying resulted in a significant moisture loss and reduced oil uptake while enhancing texture, color and taste.

2.13.2 Polysaccharide based coatings

Food gums, also called hydrocolloids, are water-soluble polymers that gelatinize and create viscous aqueous solutions. Hydrocolloids are widely employed as natural ingredients in battered products due to their functional qualities, health advantages, and nutritional (Mia Kurek and Ščetar, 2017). Food gums that have been applied interchangeably as food coating or incorporated to the chip's formulation showed a promising fat reduction and moisture retention during deep frying. However, the reduction in fat content is more dominant in fried foods (J. C. Lumanlan *et al.*, 2020). Recently, Ajo (2017) reported that the application of edible coating with xanthan gum reduced oil absorption by up to 57% and improved overall product quality such as flavor, taste and crispiness. Also, Al-Asmar *et al.* (2018) demonstrated a reduction in Maillard reaction that could decrease carcinogenic risk from fried foods with hydrocolloid coating due to the increase in water retention during frying.

The combined effects of surface tension, hydrophilicity, thermal gelation and film-forming properties of food gums have effectively reduced oil uptake in some fried foods such as sev and potato products (Mia Kurek and Ščetar, 2017). Hydrocolloids at high concentration contribute to the thickening and viscosity of the coating solution. However, food gums added to dry ingredients require more water due to high water-binding capacities to form soft dough. As a result, it decreases hardness and increases stickiness during extrusion of sev (Bajaj and Singhal, 2007).

Kim *et al.* (2011) reported that hydrocolloids at high concentration contribute to the thickening and viscosity of the coating solution. According to (Mia Kurek and Ščetar, 2017), hydrocolloids ability to lower the surface tension of water in the food affects the oil uptake with the addition of hydrocolloid coating (Fig.). Mallikarjunan *et al.* (1997) also found that hydrocolloids heated at above 60 ºC forms a protective layer and prevents the transfer of the moisture and oil during deep frying. Food without hydrocolloid coating shows more oil and moisture exchange. More water retained during deep-frying could result in less crispiness of the final product (Mia Kurek and Ščetar, 2017). The effects of thermo gelling lead to a stronger coating, reduced pore size and lower fat content of the final product (Garcıa *et al.*, 2002).

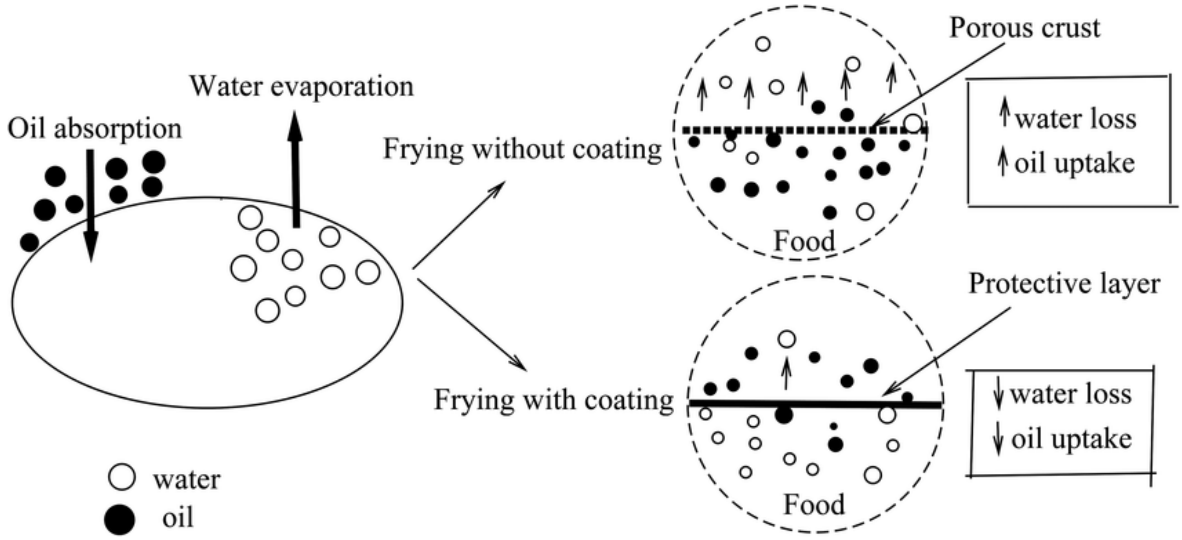

Fig 2.2: Mechanism of oil absorption with hydrocolloid

Source: Jane C Lumanlan *et al.* (2021)

2.13.3 Vacuum frying

Vacuum frying is known for enabling to fry at a low temperature and produce high product quality fried fruits by retaining the food color and nutrient content. Also, vacuum frying potato chips reduced the fat content by 13% (Ayustaningwarno *et al.*, 2018).

2.13.4 Air frying

Air frying potatoes reduced lipid content, oxidation, and nutritional quality by 70% compared to deep frying (C. S. Santos *et al.*, 2017). A novel method of frying potatoes requires only 30 g of oil per kilogram, compared to the litres of oil needed for traditional deep frying. The cost-saving benefits of using less oil in modern technologies are attracting more food companies and meeting the demand for high-quality, low-fat foods. However, expensive equipment and higher initial investment may raise the cost of fried foods (Shaker, 2014).

2.14 Edible coating

Edible coating or films are biopolymers that are hugely being investigated for the packaging and preservation of food. Edible coatings can be defined as a thin layer of edible and environmentally friendly materials that could be consumed and provide a barrier to gases, microbes and moisture to food products. Application of these films is simple, eco-friendly, highly safe and low priced which makes it promising for preserving food products. These films prevent moisture loss, aroma loss or water uptake by the food material or even penetration of oxygen which produces a good storability condition for these food products, Edible coating enhance the texture and improves the product appearance and prolong the shelf life by creating semi-permeable barriers (Oduro, 2021).

In order to reduce the fat uptake in the chips, edible coating effectiveness has been studied to coat the chips. Coating deep-fried food with edible coating causes the formation of a protective layer on the surface which can help to diminish the oil uptake in the fried food. These coating materials can be thin and invisible or thick like batter. The application of the coating is a promising route to reduce the fat uptake in the fried food product. Concerning fat uptake, properties of coating solution are aimed at reducing moisture loss and/or modification of the surface structure form upon frying. There are several ways to coat food product, such as dipping, spraying and brushing. Dipping is the most common method used to apply coatings on food materials especially when the coating solution is highly vicious, and the food materials will be dipped into coating solution for 5 to 30 s. Researchers have stated that the moisture of frying food product can be reduced up to 40% of the total product weight. Different coating materials like gelatin, gellan gum, guar gum, methyl cellulose, pectin, soy protein isolates have help in reducing the oil uptake in the fried food compared to uncoated fried food (N. Latif *et al.*, 2020).

2.15 Some edible coatings for reducing fat uptake

An edible coating is a thin layer of edible material, often no more than 0.3 mm thick, applied to the food surface in addition to or instead of natural protective coatings. Hydrocolloids are mostly utilized for frying due to their excellent gelling properties. Polysaccharides (cellulose derivate, maize starch, carrageenan, pectin, gums) and proteins (egg white, gelatin, sodium caseinate, soy protein, wheat gluten, whey protein) can be utilized as basic components, either alone or in combination (M. Kurek and Scetar, 2017). Some of the commonly used coatings are:

2.15.1 Carboxymethyl cellulose (CMC)

CMC is derived from cellulose which possesses good film forming properties and are suitable for edible coatings. Influence of CMC coating and its combination with other polymers on the quantity of the oil uptake and on the sensory attributes of potato (chips or French fries) is well reported in the scientific literatures. CMC coatings are shown to be efficient in reducing the oil uptake by 21.2% without influencing the sensory properties (21.2% and 50.4% for 1% w/v and 10% w/v coating, respectively). Moisture loss during frying decreased, and hence the oil uptake of potato products was reduced. Coating with CMC (1% w/v) and pectin (1% w/v) mixture led to a higher decrease (70%) in fat content of fried potato strips due to the synergistic effect of both hydrocolloids. Interaction between protein and starch (amylose and amylopectin) is shown to be important for the quality and for the texture of the final product. Hence, pectin and CMC can react with the elements in the cell wall (calcium) of potato and lead to a harder texture which requires a higher cutting force (M. Kurek and Scetar, 2017).

2.15.2 Pectin

Pectin, a white, amorphous, colloidal carbohydrate with a high molecular weight, is found in mature fruits, particularly apples, currants, and other fruits. Because of its thickening, emulsifying, and gel-forming qualities, pectin is utilized in fruit jellies, medications, and cosmetic products (Valdés *et al.*, 2015). In order to create composite film/coating matrices, pectin can be extracted from a variety of plant sources, typically from by-products of food processing, and utilized to create edible films and coatings. To stabilize and alter the rheology of food, pectin and alginate are commonly utilized in food systems. Gelation, which results from intermolecular interaction with polyvalent cations, is the most advantageous feature. Due to their effectiveness as an edible covering to keep lipids, oxygen, and carbon dioxide out of fried food, a number of food hydrocolloid varieties have been studied for their ability to minimize oil absorption (Albert and Mittal, 2002).

Pectin treated chips had better organoleptic attributes and crunchiness than CMC treated samples and reduced acrylamide content (around 33%). In addition, higher reduction of acrylamide in fried chips up to 91.9% was achieved due to a synergic effect of pectin and blanching treatments (M. Kurek and Scetar, 2017).

2.15.3 Starch

Starch is a readily available and affordable natural polymer. It is composed primarily of amylose and amylopectin, which is heavily branched and has a high molecular weight. Amylose is a better film-forming component because of its linear structure. As a result, coatings can be created from any amylose-containing starch (Kramer, 2009). Angor *et al.* (2013) found that the starch edible coating at different levels (from 1% to 5% w/v) reduced fat absorption of potato pellet chips (up to 27%). Starch coatings at different levels also improved sensory attributes of potato chips.

2.15.4 Xanthan

Xanthan gum is an extracellular polysaccharide generated through submerged aerobic fermentation of a pure *Xanthomonas campestris* culture. It is frequently utilized in the food sector due to its excellent film-forming qualities, including high viscosity even at low with the cellulose derivatives, xanthan gum had a lower impact on decreasing the oil uptake in French fries Daraei Garmakhany *et al.* (2014) found that 0.5% (w/v) xanthan coatings reduced the oil uptake in potato chips by 24.8%. Pahade and Sakhale (2012) reported only a 6% reduction (for 1% (w/v) coating.

2.15.5 Guar gum

Guar gum, a galactomannan obtained from the Indian cluster bean (*Cyamopsis tetragonoloba (L.) Taub*), is a water-soluble polysaccharide. Gum based coatings can enhance the barrier properties of fried potato chips by lowering the formation of pores and cracks in the fried food. When the polymer concentration is increased, more coating solution remains on the sample, so likewise coating pick-up percentage increases (M. Kurek and Scetar, 2017). The backbone of guar gum is a linear chain of b 1,4- linked mannose residues to which galactose residues are 1,6- linked at every second mannose, forming a short side-branches. The application of a guar gum as a coating agents on the quantity of oil uptake and on sensory attributes of potato is well investigated (Daraei Garmakhany et al., 2014; Kim et al., 2011; Pahade & Sakhale, 2012; Yu, Li, Ding, Hang, & Fan, 2016). Izadi et al. (2015) found that there were no significant differences between CMC and guar gum with similar concentrations in the coating pick-up in shrimps after deep fat frying. In addition, the lightness of the samples was decreased by increasing the guar gum concentration, so the darkest colour was observed in the coated shrimps with 1.5% guar gum solution.

Properties of guar gum

2.15.5.1.1 Film-forming ability

Guar gum can form a cohesive film on the surface of potato slices, acting as a barrier to oil penetration during frying. This film reduces the contact between the oil and the potato tissue, thereby decreasing oil uptake (Yu *et al.*, 2016).

2.15.5.1.2 Water-holding capacity

The hydrophilic nature of guar gum allows it to retain moisture effectively. Maintaining surface moisture during frying can delay the formation of pores that facilitate oil absorption (Daraei Garmakhany *et al.*, 2014).

2.15.5.1.3 Thermal stability

Guar gum remains stable at typical frying temperatures (160–180°C), ensuring that its barrier properties are maintained throughout the frying process (Jia *et al.*, 2017).

2.15.5.1.4 Gel-forming properties

In the presence of water, guar gum forms a gel that can be applied as a coating to potato slices. This gel acts as a protective layer, reducing the formation of surface cracks and pores that lead to increased oil uptake (Jane C Lumanlan *et al.*, 2021).

2.15.5.1.5 Viscosity enhancement

Even at low concentrations, guar gum significantly increases the viscosity of coating solutions, ensuring an even and uniform application on potato slices. This uniformity enhances the effectiveness of the oil barrier (Yu *et al.*, 2016).

2.15.5.1.6 Interaction with Starch

Guar gum interacts synergistically with the native starches in potatoes, strengthening the film formed on the surface and further reducing oil uptake (Daraei Garmakhany *et al.*, 2014).

2.15.5.1.7 Non-Toxic and Edible

As a food-grade additive, guar gum is safe for consumption and does not introduce harmful substances into the final product (Jia *et al.*, 2017).

2.15.5.1.8 Surface Adhesion

Guar gum exhibits good adhesion to the surface of potato slices, ensuring that the coating remains intact during the frying process (Yu *et al.*, 2016).

2.15.5.1.9 Reduction of Oil Uptake

Studies have demonstrated that coatings containing guar gum can significantly reduce oil absorption in fried potato products. For instance, incorporating glycerol with guar gum resulted in a 51.8% reduction in oil absorption in potato chips (Yu *et al.*, 2016).

2.15.5.1.10 Effects on Sensory Qualities

Guar gum coatings have been found to improve the texture and crispness of fried potato products without adversely affecting flavor or aroma, thereby enhancing consumer acceptability (Jia *et al.*, 2017).

Part III

Materials and methods

3.1 Materials

3.1.1 Raw materials

Large and oval shaped potatoes of khumal upahar variety with shallow and few numbers of eyes were collected from market of Dharan. Potatoes were yellowish brown in external appearance and variable in size and weight. The sampling was done randomly during procurement. PE bags were used for holding samples during collection. Sample was stored at an ambient temperature of 27-32ºC during the course of experiment.

3.1.2 Palm oil

Refined Bleached and Deodorized (RBD) Palm oil of AV and PV less than 0.3 and 3 respectively used for the frying purpose was obtained.

3.1.3 Guar gum

Guar gum was collected from CG Food Industries Sunsari.

3.1.4 Equipment and chemicals

Equipment and chemicals required were utilized from Central Campus of Technology laboratory which are given in Appendix D.1 and D.2.

3.2 Methods

3.2.1 Processing procedures

3.2.1.1 Cleaning

Potatoes were washed in tap water to remove adhered soil and other impurities.

3.2.1.2 Peeling and slicing

Peeling was done with the help stainless steel knives. The peeled potatoes were sliced to 1.5mm thick slices with the help of potato slicer.

3.2.1.3 Washing of slices

Potato slices were washed in tap water for the leaching of surface sugars.

3.2.1.4 Blanching and sulphiting of potato slices

All the samples (washed potato slices) wrapped in muslin cloth and dipped into water at 80-85ºC containing for 4 min (Kapadiya *et al.*, 2018). Blanched slices were then cooled in tap water and then they were treated with 2000 ppm potassium metabisulphate (KMS) for 10 minutes to prevent non-enzymatic browning during drying and frying operations (Gupta, 2023).

3.2.1.5 Pre drying of slices

Potato slices were spread on a single layer tray with space between slices for air movement and dried in dryer at 60°C for 30, 60 and 90min at approx. 30% RH (Cruz *et al.*, 2018).

3.2.1.6 Preparation of coating solution

Guar gum (0.25, 0.5.0.75, and 1 %) were mixed in sufficient distilled water (80-90ºC) to make the coating suspensions of different concentrations and were homogenized with the help of food processor (N. A. M. Latif *et al.*, 2020). The coating suspensions were brought to room temperature for further use.

3.2.1.7 Dipping in coating solutions

Samples were then immersed in different coating solutions (100 gm slice in 500 ml solution) at room temperature for 1 minute (N. A. M. Latif *et al.*, 2020). Excessive gums were then drained out.

3.2.1.8 Surface air drying

Coated samples were then spread on trays and dried for 10 minutes at 60 ºC (Zhang and Fan, 2021). This step prevents excessive coating loss during frying, improves adhesion, and ensures uniformity in the final product.

3.2.1.9 Frying

All the samples were fried in refined palm oil at 180±5°C for 3 minutes (Cruz *et al.*, 2018). The fresh (uncoated, undehydrated) samples were taken as control. Chips were then allowed to cool. The adhered oil is removed by spreading the chips on blotting paper and then packaged in PP pouch.

Potato

↓

Washing

↓

Peeling and slicing (1.5mm thick)

↓

Washing of slices

↓

Blanching (80-85 ºC for 4 minutes) and sulphiting (2000 ppm KMS)

↓

Draining extra moisture

↓

Frying (180±5°C for 3 minutes)

↓

Cooling to room temperature

↓

Packaging in PP

Fig.3.1 Flow chart for the preparation of control sample

Source: A. D. Garmakhany *et al.* (2008)

Potato

↓

Washing

↓

Peeling and slicing (1.5mm thick)

↓

Washing of slices

↓

Blanching (80-85°C for 4 min.)

↓

Sulphiting (2000 ppm KMS for 10 min.)

↓

Pre drying at 60°C for 30, 60 and 90 min

↓

Dipping in coating solutions (0.25, 0.5, 0.75, and 1 %) for 1 min.

↓

Surface drying for 10 minutes at 60°C

↓

Frying at (180 ±5°C) for 3 min

↓

Cooling to room temperature

↓

Packaging in PP

Fig 3.2 Flow chart for the preparation of different samples

3.2.2 Analytical procedure

3.2.2.1 Chemical analysis of raw materials and product

3.2.2.1.1 Determination of Crude fat

Fat content of potato and potato chips was determined by Soxhlet apparatus as described in Ranganna (1986).

3.2.2.1.2 Determination of Crude fiber

Crude fiber of potato and potato chips was determined by the method given by Ranganna (1986).

3.2.2.1.3 Determination of Crude protein

Protein content of potato and potato chips was determined by kjeldahl method as given in Ranganna (1986).

3.2.2.1.4 Determination of Total ash

Ash content of potato and potato chips was determined as described in Ranganna (1986).

3.2.2.1.5 Determination of Moisture

Moisture content of raw material and product was determined as per the methods described by Ranganna (1986).

3.2.2.1.6 Determination of Carbohydrate

Total carbohydrate was calculated by difference, that is the percentage of moisture, ash, protein, and fat was subtracted from 100 % according to Ranganna (1986).

% carbohydrate = 100 – (moisture + protein + crude fat + crude fiber + ash)

3.2.2.1.7 Determination of Acid value

Acid value of oil was analysed according to Ranganna (1986).

3.2.2.1.8 Determination of Peroxide value

Peroxide value of oil was analysed according to Ranganna (1986)..

3.2.2.1.9 Determination of Iodine value

Iodine value of oil was analysed according to Ranganna (1986)..

3.2.2.1.10 Reduction of fat uptake due to coating

The reduction of fat uptake in potato chips due to pectin coating on different concentrations are calculated by the formula followed by A. Garmakhany *et al.* (2008) in their study.

$$\text{Reduction of fat uptake due to coating} = \frac{\text{Fat uptake(noncoated)} - \text{fat uptake(coated)}}{\text{fat uptake (noncoated)}}$$

3.2.2.2 Storage stability of Potato chips

3.2.2.2.1 Determination of moisture content:

According to Ranganna (1986), the ground chip was weighed and placed petri-disc and fixed weight was noted. It was then dried in hot air oven at 105 ± 2 ºC for 1 h to constant weight. Disc with dried sample was firstly cooled in desiccators to room temperature and then weighted and again dried, cooled and weighed until constant weight was achieved. Then the moisture content was calculated by using following equation.

3.2.2.2.2 Determination of peroxide value (PV):

According to Ranganna (1986), oil was extracted from the chips, solvent were removed and cooled. Fixed weight of oil (about 5gm) was taken in Iodine flask. 35 ml of solvent mixture (i.e., acetic acid glacial and chloroform 3:2 v/v) was added and flask was swirled until the sample dissolved (approx.1 min). 1 ml of saturated potassium iodide (KI) was added by 1ml pipette and 30 ml of distilled water and 1ml of freshly prepared starch solution were added, then the mixture was titrated with 0.1N Sodium thiosulphate (Na2S2O3) solution with constant and vigorous shaking, until blue color completely disappeared.

The peroxide value is calculated using the following equation.

$$\text{PV (meqv O2/kg of oil)} = \frac{\text{N} \times (\text{Vs} - \text{VB}) \times 1000}{\text{Weight of sample (g)}}$$

Where, N= normality of sodium thiosulphate,

Vs= sod-thiosulphate consumed by sample (ml) and

VB = sod-thiosulphate consumed by blank (ml)

3.2.2.2.3 Determination of Acid value

The acid value was determined according to Ranganna (1986). 3 gm oil was accurately weighed in 250 ml conical flask. About 50 ml previously neutralized ethanol (95 %) was added and warm to about 70 ºC and a drop or two drop of phenolphthalein indicator (1 %, alcoholic) was added and titrated with 0.1N sodium hydroxide solution shaking vigorously. The end point was indicated by a pink color persisting at least 30 seconds.

The acid value was calculated using the following equation

$$\text{Acid value(mg of KOH/g of oil)} = \frac{\text{ml of alkali} \times \text{N of alkali} \times 56.1}{\text{weight of sample (g)}}$$

Where, N= Strength of sodium hydroxide solution

3.2.3 Sensory evaluation

Sensory evaluation was carried out using 9-point hedonic scale described by Ranganna (1986). Sensory panellists were semi trained panellists from Central Campus of Technology, Dharan. The parameters for sensory evaluation were texture, appearance, colour, taste and overall acceptability. The specimen of the evaluation of card is shown in Appendix A.

3.2.4 Statistical analysis

ANOVA (Analysis of variance) was used to analyze the data from the sensory evaluation. The Genstat release 12.1 software program developed by VSN International Ltd. was used to analyze the significant differences between them using LSD at the 5 % level of significance, and Microsoft Excel 19 was used to perform a t-Test. The results of the chemical analysis of the best and control chips were statistically analysed using the t-Test.

Part IV

Results and discussion

The guar gum coated potato chips were prepared at Central Campus of Technology, Dharan, in a laboratory for the present study. The guar gum coated potato chips were prepared by coating 0, 0.25, 0.50, 0.75, and 1 % guar gum on potato. Potatoes were washed peeled and cut into strips of thickness 1.5mm. After that, sulphiting was performed by dipping potato slices on potassium metabisulphite (KMS) solution. After that it was pre dried at 60°c for 30, 60 and 90 minutes. Then, it was dip in the guar gum solution at 27±3°C for 1 minutes. The slices were drained and then air dried for few minutes. The coated potato chips were then fried in palm oil at 180±5 °C for 3 minutes.

4.1 Chemical composition of potato

Raw potatoes obtained from Dharan market which were used for the preparation of low-fat potato chips were analysed for moisture content, protein content, ash content, crude fibre, reducing sugar and total sugar and their respective findings are given in table 4.1. The mean value of three determinations of moisture contents of the potatoes was found to be 81.086 with the standard deviation of 1.061.

Table 4.1: Chemical composition of potato

Parameters	Value % (db)
Crude protein	9.09±0.426
Ash content	4.09±0.0.803
Crude fibre	4.55±0.260
Crude fat	0.45±0.054
Carbohydrates	81.82±1.275

*Values in the table are arithmetic mean of triplicate samples. Figure in the parentheses indicates standard deviation.

The proximate analysis of the raw potato for various parameters like moisture content (%), crude protein (%), crude fat (%), crude fibre (%), ash (%) and total carbohydrates (%) (in dry basis except moisture content) were found to be 81.086 %, 9.09 %, 0.45 %, 4,55 %, 4.09 % and 81.82 % respectively as given in Table 4.1. DFTQC. (2012) reported respective proximate values to be 74.7%, 6.32%, 0.4%, 2.37%, 2.35 %, and 88.54% respectively. Similarly, the respective proximate values reported by USDA. (2018) were 79.25 %, 9.74%, 0.43 %, 2.65 %, 5.11% and 84.71% respectively. Our data was in the range as given by DFTQC. (2012) and USDA. (2018). The moisture, protein content, fat content , fiber content and ash content was a little higher than the value reported by DFTQC. (2012). The protein content, fat content, ash content and carbohydrates was in similar to the value reported by USDA. (2018). Similar results were obtained by (Toma *et al.*, 1978; Vaitkevičienė, 2019)The difference in proximate composition may be due to factors like varieties, climatic conditions, soil type, maturity, fertility and others.

4.2 Physiochemical characteristics of Palm olein

The physiochemical characteristics of palm olein are shown in Table 4.2.

Table 4.2: Physiochemical characteristics of palm olein

Parameters	Value(db)
Acid value (mg of KOH/g of oil)	0.142 ± 0.13
Peroxide value (meqv O_2/kg of oil)	1.19 ± 0.34
Iodine value (g I_2 / 100g oil)	54.79 ± 1.41
Moisture content (%)	0.032 ± 0.011
Melting Point (°c)	20.42 ± 1.02

*Values are in dry basis.

The acid value, peroxide value and iodine value of palm oil from our study was found to be 0.142 mg of KOH/g of oil, 1.19 meqv O_2/kg of oil and 54.79 respectively. The data from our study was in range of the standard value of palm oil given by DFTQC. (2022). The acid value, peroxide value and iodine value of palm oil by DFTQC. (2022) were <6mg of KOH/g of oil, <10 meqv O_2/kg of oil and 48-56 respectively.

4.3 Percentage of fat content and moisture content of control sample

The initial water content of fresh potato chips (before frying) was 81.086 g/100 g (wet basis). After frying the oil content of the potato chips was 46.269 g oil/100 g (wet basis) and the water content was 2.512 g water/100 g (wet basis).

Table 4.3: Fat and moisture content of control sample

S.N.	Parameters	value*
1	Fat content	46.269 ± 0.05
2	moisture content	2.512 ± 0.014

*Values are the means of three different determinations. Figures in parentheses are the standard deviations. These values are in accordance with the values obtained by W. A. Gould (1999).

4.4 Effects of pre-drying and guar gum on oil uptake of potato chips.

Effects of pre-drying and guar gum on oil uptake of potato chips is shown in table below:

Table 4.4: Effect of pre-drying and guar gum on oil uptake of potato chips

Pre-drying time (min)	Guar gum (%)	Fat content (% db)	Reduction in oil uptake (%)
0 min (control)	0%	46.27 ± 0.05	-
30 min	0.25%	38.09 ± 0.03	17.65
30 min	0.50%	34.01 ± 0.09	26.52
30 min	0.75%	27.49 ± 0.02	40.56
30 min	1%	32.52 ± 0.04	29.72
60 min	0.25%	32.75 ± 0.03	29.21
60 min	0.50%	26.52 ± 0.06	42.71
60min	0.75%	25.76 ± 0.04	44.34
60 min	1%	27.76 ± 0.04	40
90 min	0.25%	31.00 ± 0.03	33
90 min	0.50%	24.27 ± 0.06	47.58
90 min	0.75%	23.02 ± 0.05	50.28
90 min	1%	24.00 ± 0.04	48.13

*Values are the means of triplicates and figures in the parenthesis are standard deviation of the triplicates.

The above Table 4.4 shows that control potato chips absorbed significantly more oil/fat compared to all coated potato chips. Similar observations were observed by Hua *et al.* (2015) in coated potato strips. The oil content in the chips can be affected by the frying temperature and the type of oil used during frying the chips. Moisture removal by evaporation during a frying process makes void spaces within the food which become filled with oils, thus increasing the oil content of fried foods (Maity *et al.*, 2015). The fat content was maximum for control and minimum for 0.75 % guar gum coated with 90 min pre dried potato chips i.e., 46.27 % and 23.02% respectively.

Pre drying the potato slices and coating the slices with guar gum produced a significant reduction in oil absorption, as reflected by the reduction in oil content compared to the control treatment. All the coated samples had a lower oil uptake than uncoated samples. This can be due to lower moisture loss of coated samples during frying and therefore, lower oil uptake (Mirzael *et al.*, 2015). In the present study the voids were not vacant due to the hydrocolloid pre-treatment for absorption of the oil, thus the oil uptake was reduced significantly. Sothornvit (2011) showed very less oil uptake in fried potato chips treated with guar gum. The reduction in oil uptake was higher in 90 minutes pre dried slices coated with 0.75 % guar gum i.e. 50.28 %.

4.5 Sensory evaluation of potato chips

Samples of control and potato chips with lowest fat content obtained from using different pre drying time and guar gums concentration were evaluated for quality attributes: color, taste, texture, appearance and overall acceptability on a 9-point Hedonic scale. Six samples with highest reduction in oil uptake were evaluated for sensory attributes. The samples with low fat content are coded as given below.

Table 4.5: Samples selected for sensory evaluation of potato chips

Pre drying time	Guar gum concentrations	Fat content %	Sample code
30 min	0.75%	27.49 ± 0.02	A
60 min	0.50%	26.52 ± 0.06	B
60 min	0.75%	25.76 ± 0.04	C
90 min	0.25%	24.27 ± 0.06	D
90 min	0.50%	24.00 ± 0.04	E
90 min	0.75%	23.02 ± 0.05	F
0 min	0%	46.27 ± 0.05	G

4.5.1 Appearance

The mean sensory score for appearance were found to be 6.33, 8.00, 8.89, 7.00, 7.67, 7.00 and 6 for the chip's formulations A, B, C, D, E, F, and G respectively. Statistical analysis showed that pre drying and guar gum coating on potato had significant effect ($p < 0.05$) on the appearance of the different chip formulations. The sample E was significantly different ($p < 0.05$) with other samples; sample D and sample F were similar to each other which are shown graphically in Figure. 4.1. The sample C got the highest score and sample g got the lowest score than other samples.

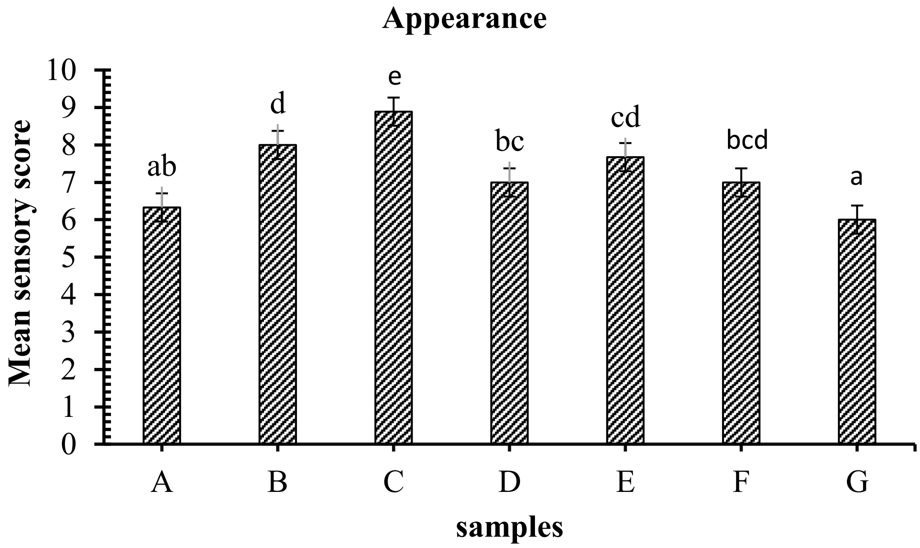

Fig 4.1: Mean sensory scores for appearance of guar gum coated potato chips

*A, B, C, D, E, F and G denote potato chips selected for sensory evaluation. Vertical error bars represent the value of standard deviation. Values of same subscript represents that the samples were similar in terms of appearance.

Pre-drying plays a crucial role in enhancing the appearance of fried potato products. Pre-drying reduces the initial moisture level, minimizing the production of surface flaws like blisters and ensuring a more uniform color development during frying. Cruz *et al.* (2018) found that pre-drying reduced oil content and enhanced texture, contributing to an improved appearance. Guar gum coating has a considerable effect on the appearance of fried potato chips. Guar gum forms a thin, uniform layer on the surface, acting as a barrier against oil absorption and moisture loss while frying. This barrier not only limits oil absorption, but it also promotes even browning and eliminates surface flaws. Jia *et al.* (2017) found that coatings containing guar gum and sorbitol successfully reduced oil absorption while maintaining the structural integrity of fried potato chips, resulting in a more appealing look. Additionally,Yu *et al.* (2016) observed a significant reduction in oil absorption in potato chips coated with guar gum, which correlated with improved sensory attributes, including appearance. Additionally, extended pre-drying may promote non-enzymatic browning reactions, leading to darker coloration that may be less appealing to consumers (Cruz *et al.*, 2018). Applying guar gum coatings at high concentrations can lead to the formation of a thick, viscous layer on the potato surface. This excessive coating may impede proper moisture evaporation during frying, resulting in a soggy texture. Moreover, a thick guar gum layer can interfere with the development of the characteristic golden-brown color of fried products, leading to an unappealing appearance. The low score of sample D , E and F than sample B and C could be correlated with (Cruz *et al.*, 2018).

4.5.2 Color

The mean sensory score for color were found to be 7.111, 8.111, 8.667, 7.333, 7.778, 6.667 and 5.667 for the chips formulations A, B, C, D, E, F, and G respectively. Statistical analysis showed that pre drying and guar gum coating on potato had significant effect ($p < 0.05$) on the color of the different chip formulations. Samples A, B, C, D, E, F, and G were significantly different ($p < 0.05$) to each other which is shown graphically in Figure. 4.2. The sample C got highest score and sample G got lowest score than other samples.

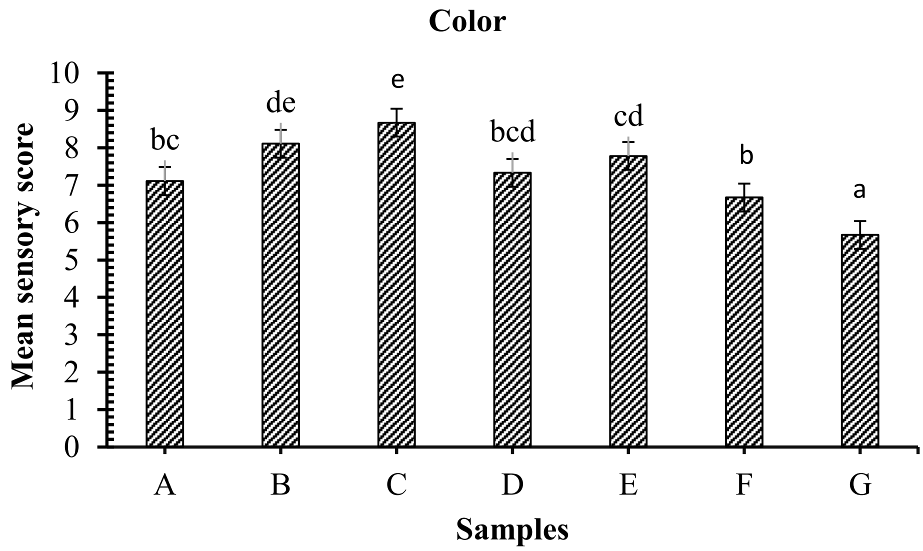

Fig 4.2: Mean sensory scores for color of guar gum coated potato chips

*A, B, C, D, E, F and G denote potato chips selected for sensory evaluation. Vertical error bars represent the value of standard deviation. Values of same subscript represents that the samples were similar in terms of color.

Pre-drying reduces the moisture content of potato slices prior to frying, which can have a significant impact on the color of the finished product. According to a study by (Cruz *et al.*, 2018) , pre-drying and frying periods have a direct impact on the color characteristics of potato chips, with pre-dried samples having higher color quality. The reduction in moisture content through pre-drying minimizes the water–oil mass transfer gradient during frying, leading to less oil uptake and increased color development. The application of guar gum forms a barrier that affects heat and mass transfer during frying, potentially influencing the Maillard reaction responsible for browning (Yu *et al.*, 2016). Sample C with 60 min pre drying and 0.75 % guar gum coating may have got the highest score due to the synergistic effect of reduced moisture and an effective coating barrier. However, excessive pre-drying or high concentrations of hydrocolloid coatings may adversely affect the desired color attributes, indicating the need for optimization which can be observed in sample F. Similar pattern of results were reported by (J. S. P. d. Santos *et al.*, 2023) as in present study.

4.5.3 Texture

The mean sensory score for texture were found to be 6.556, 7.667, 8.22, 6.22, 9.00, 6.00 and 5.00 for the chips formulations A, B, C, D, E, F, and G respectively. Statistical analysis showed that guar gum coating on potato had significant effect ($p < 0.05$) on the texture of the different chip formulations. The sample D and F were similar to each other which is shown graphically in Figure. 4.3. The sample E got highest score than other samples. Samples B, C, E and G were significantly different ($p < 0.05$) with each other. Sample E got the highest score followed by sample C and sample G got the lowest score among other samples.

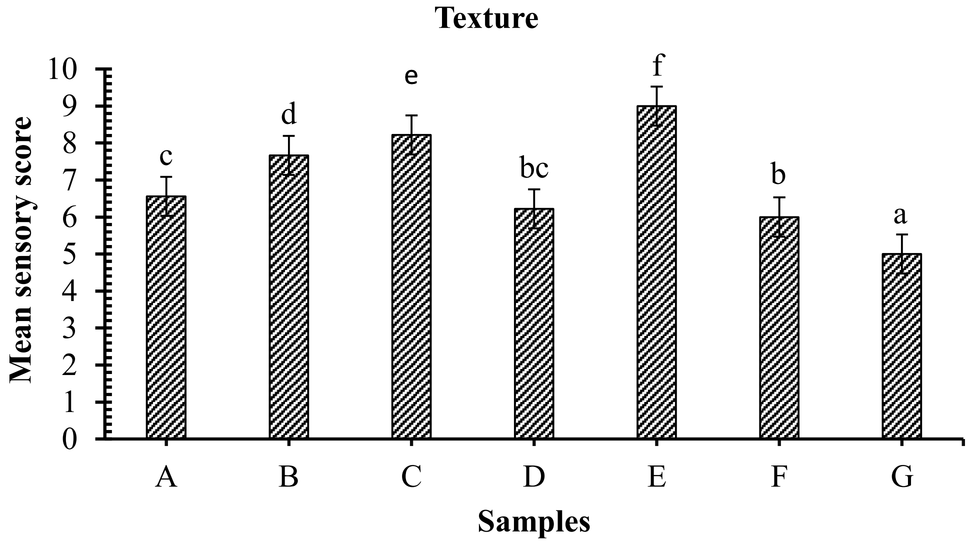

Fig 4.3: Mean sensory scores for texture of guar gum coated potato chips

*A, B, C, D, E, F and G denote potato chips selected for sensory evaluation. Vertical error bars represent the value of standard deviation. Values of same subscript represents that the samples were similar in terms of texture.

The analysis of variance revealed that pre-drying time and guar gum content had significant effects on the texture of potato chips ($p < 0.05$). Sample G (control: no pre-drying, 0% guar gum) exhibited the lowest mean score (5.000), suggesting that the absence of pre-drying and hydrocolloid application led to a lack of structural integrity and crispness in the chips. This finding aligns with research conducted by (J. S. P. d. Santos *et al.*, 2023) which demonstrated that hydrocolloid coatings improve textural properties by forming a protective barrier, reducing oil absorption, and enhancing crispness. The highest texture score (9.000) was observed in Sample E (90 min pre-drying, 0.50% guar gum). This could be due to an optimal balance between moisture reduction and guar gum concentration, allowing the chips to achieve superior crispness without becoming overly hard. Previous studies by (Hua *et al.*, 2015) have shown that moderate drying and hydrocolloid coatings improve the mechanical properties of fried products by minimizing surface damage during frying. Similarly, Samples B and C (60 min pre-drying with 0.50% and 0.75% guar gum, respectively) demonstrated high texture scores (7.667 and 8.222), indicating that moderate pre-drying combined with balanced guar gum concentrations positively influences texture. the texture scores of Sample

A and Sample D (6.556 vs. 6.222) were not significantly different. Sample D (90 min pre-drying, 0.25% guar gum) likely had insufficient guar gum concentration to compensate for the adverse effects of prolonged pre-drying. Huang et al. (2020) also noted that lower hydrocolloid concentrations in combination with extended drying could result in suboptimal textural attributes.

4.5.4 Taste

The mean sensory score for taste were found to be 6.556, 8.333, 8.778, 7.333, 7.556, 7.000, and 6.444 for the chips formulations A, B, C, D, E, F, and G respectively. Statistical analysis showed that pre drying and guar gum coating on potato had significant effect ($p < 0.05$) on the taste of the different chip formulations. Samples G and A were not significantly different from each other ($p > 0.05$) and similar to sample F and D, which is shown graphically in Figure. 4.4. Sample C, which had moderate pre-drying time and optimal guar gum concentration, received the highest score for taste.

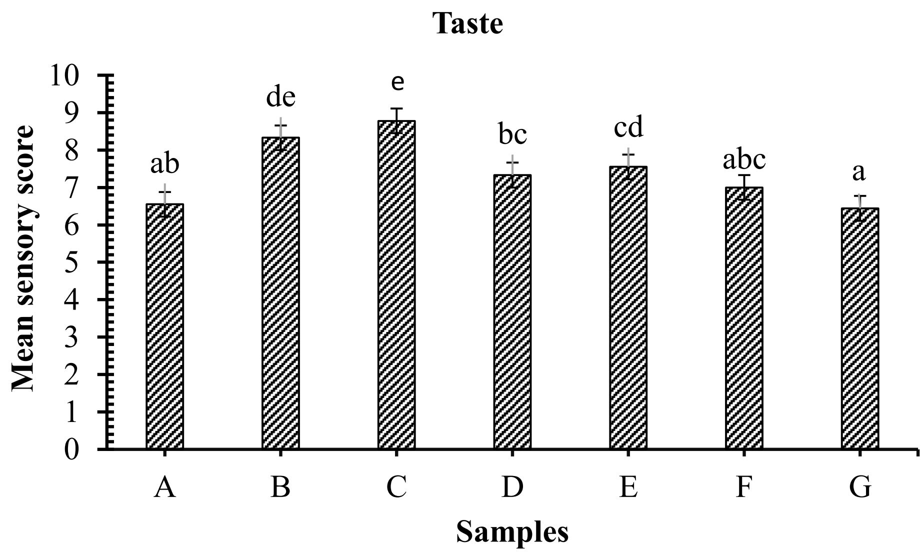

Fig.4.4: Mean sensory scores for taste of guar gum coated potato chips

*A, B, C, D, E, F and G denote potato chips selected for sensory evaluation. Vertical error bars represent the value of standard deviation. Values of same subscript represents that the samples were similar in terms of taste.

Samples G and A were not significantly different from each other ($p > 0.05$). This may be due to the fact that sample A's less pre-drying time slightly reduced surface moisture, which could enhance crispness, but the low guar gum concentration was insufficient to form a protective barrier against oil absorption or effectively retain natural flavors. Sample G's high moisture content diluted the Maillard reaction products responsible for flavor and allowed excessive oil uptake, resulting in a greasy texture. Similar results were reported by (Hua *et al.*, 2015) and (Kita *et al.*, 2007). Extended pre-drying durations (60–90 minutes) and higher concentrations of guar gum (0.50–0.75%) notably improved taste ratings. These specific conditions lowered the water activity, concentrated the starches and sugars, and facilitated the Maillard reaction during frying, thus enhancing flavor development (Bouaziz et al., 2016). Moreover, the ability of guar gum to create a protective layer reduced oil absorption and maintained the natural flavor of the potatoes, particularly in samples containing 0.50% and 0.75% guar gum (Santos et al., 2023). The combined effects of decreased oiliness and enhanced texture likely led to a better taste experience in these samples.

4.5.5 Overall acceptability

The mean sensory score for appearance were found to be 6.444, 8.00, 9.00, 7.22, 7.56, 7.00 and 6.00 for the chips formulations A, B, C, D, E, F and G respectively. Statistical analysis showed that guar gum coating on potato had significant effect ($p < 0.05$) on the overall acceptability of the different chip formulations. The sample D and F were to each other. Sample C was significantly different ($p < 0.05$) with other samples which are shown graphically in Figure. 4.5. The sample C got highest score than other samples in terms of overall acceptability.

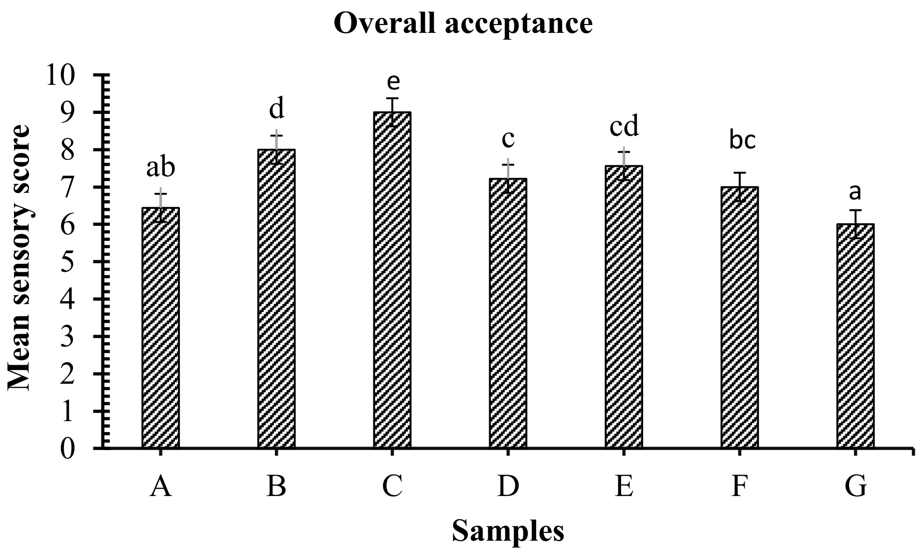

Fig.4. 5 Mean sensory scores for overall acceptance of guar gum coated potato chips

*A, B, C, D, E, F and G denote potato chips selected for sensory evaluation. Vertical error bars represent the value of standard deviation. Values of same subscript represents that the samples were similar in terms of overall acceptability.

Control chips recorded lower scores as they were perceived oily. The edible coatings have retained more moisture and less lipid inside of fried chips, thereby generating different mouth-feelings (Hua *et al.*, 2015).

Samples that underwent longer pre-drying durations (60–90 minutes) and included higher concentrations of guar gum (0.50–0.75%) demonstrated significantly improved performance, with Sample C (60 minutes of pre-drying and 0.75% guar gum) receiving the highest rating. The overall acceptability of sample C was higher due to the improvement in color, taste and texture with respect to other samples. This improvement can be attributed to the effective reduction of moisture, which enhanced crispness and minimized oil absorption, while the optimal concentration of guar gum preserved the natural potato flavor and texture (Hua *et al.*, 2015; J. S. P. d. Santos *et al.*, 2023). The overall sensory evaluation result for uncoated potato chips was the lowest due to pale color, less crispy and plain taste chips. The addition of pre drying and coating not only impact in reducing the fat content potato chips but it also provided slightly improvement of the sensory attributes. Therefore, from the sensory evaluation of the product conducted on the attributes like appearance, color, texture, taste and overall acceptability, the sample coated with 0.5 % guar gum and pre dried for 60 minutes was rated as best in all attributes.

4.6 Proximate analysis of best product

Thus, from statistical sensory analysis, the best product was found to be sample C pre dried for 60 minutes and containing 0.75% guar gum coating on potato chips. Proximate analysis of sample G (Control, 0 min pre dried and 0 % guar gum) and sample C (Best) was done. The value of proximate analysis is shown in Table 4.4.

Table 4.6 Proximate analysis of product

Parameters	Sample G (Control)	Sample C (Best)
Moisture	$2.512^{a} \pm 0.014$	$2.80^{b} \pm 0.016$
Crude protein (%, db)	$5.815^{a} \pm 0.051$	$6.025^{b} \pm 0.062$
Crude fat (%, db)	$46.269^{a} \pm 0.05$	$25.760^{b} \pm 0.030$
Crude fiber (%, db)	$3.015^{a} \pm 0.050$	$3.810^{b} \pm 0.052$
Total ash (%, db)	$2.058^{a} \pm 0.013$	$2.099^{b} \pm 0.015$
Carbohydrates (by difference)	$42.843^{a} \pm 0.115$	$62.306^{b} \pm 0.121$

*Values in the table are arithmetic mean of triplicate samples. Figure in the parentheses indicates standard deviation. Values in the column having different superscripts are significantly different at 5 % level of significance.

The moisture content, crude protein, crude fat, crude fiber, ash and carbohydrate of sample G (Control) were found to be 2.512 %, 5.815 %, 46.254%, 3.015 %, 2.058 %, and 42.843% respectively. The moisture content, crude protein, crude fat, crude fiber, ash and carbohydrate of potato chips as reported by USDA. (2019) were 1.8 %, 3.57 %, 35.7%, 3.6%, 1.48 % and 53.6 %. The crude fiber and carbohydrate content of control chips from our study was found to be lower and moisture, fat, protein, and ash content was found to be higher than the value reported by USDA. (2019). Also, similar result was obtained by Deboch and Mezgebe (2023).

The moisture content, crude protein, crude fat, crude fiber, ash and carbohydrate of sample C (Best) were found to be 2.801 %, 6.025 %, 25.760 %, 3.810%, 2.099 % and 62.306 % respectively. There was significant increase in moisture content of sample C with respect to sample G. Increase in water content due to coating, may be result of barrier properties of coating agents which prevent water loss during frying and by this mechanism water content of coated chips were higher than non-coated chips (Mirzael *et al.*, 2015). Guar gum treated potato chips appeared to be significantly lower in fat content than the control potato chips. Similar result was obtained by S. Paramasivam *et al.* (2022). It was also observed that the lower oil content correlated with the higher moisture content in potato chips, since oil absorption happens as moisture is removed from the food during the frying process (M Mellema, 2003). The fiber content and protein content of the best sample increases than the control. There was no significant difference in ash content of the control and best sample. Guar gum coating affect the protein and fiber content. There was significant increase in the carbohydrate content of the guar gum coated potato chips than control.

4.7 Storage stability of the product

The best product (Sample C) of guar gum coated potato chips was found best with respect to appearance, colour, taste and overall acceptance. Hence it was subjected to further study for the storage stability evaluation in the laboratory. The potato chips were packed in PP packaging and storage stability was studied for 40 days with triplicate samples. The samples were stored in room temperature (27 ± 3 °C). The moisture content of the product, acid value and peroxide value of the extracted fat, was evaluated from the date of manufacture up to 40 days as follows:

4.7.1 Moisture content

The moisture content of the sample (control) was observed to be 2.512 % at initial which reached 2.655, 2.928, 3.236 and 3.528 % within 10, 20, 30 and 40 days respectively. Similarly, for sample C (best) the moisture content was observed to be 2.801% at initial which reached 2.932, 3.152, 3.377 and 3.61% within 10, 20, 30 and 40 days respectively.

The change or increasing trend of moisture content of sample control and sample C is shown in Figure. 4.6.

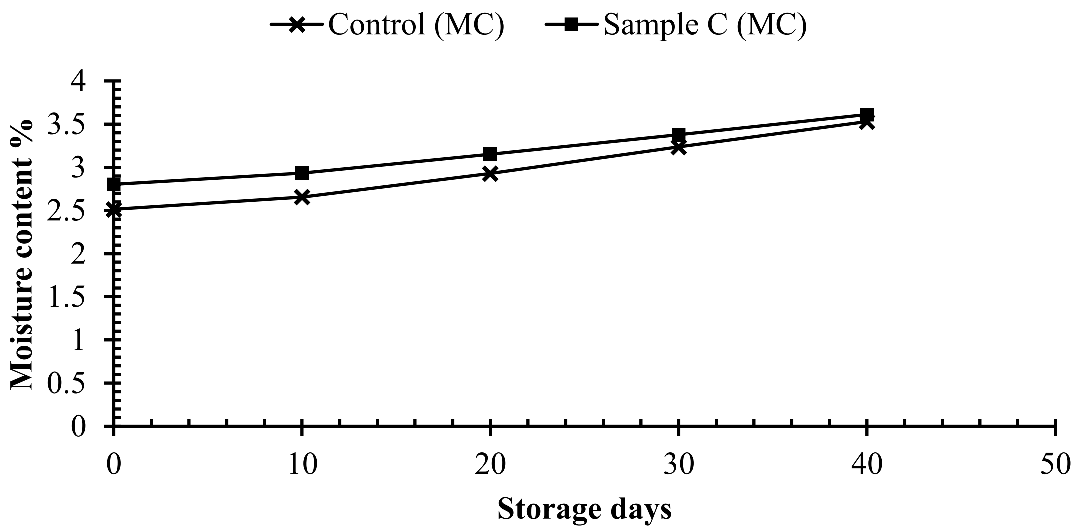

Fig.4.6 Change in moisture content during storage of control and best sample

Statistical analysis using a paired t-test demonstrated a significant difference between the two samples, with Sample C exhibiting a mean moisture content of 3.1744% compared to 2.9718% for the control. The variance was lower in Sample C, indicating greater stability in moisture content, which suggests that the guar gum coating effectively reduces moisture uptake during storage. The t-statistic (two-tailed), confirms that there is a significant effect ($P<0.05$) of difference at 5% level of significance between the moisture contents of the two samples. This finding is in line with the study conducted by (Kolagi *et al.*, 2021).

The initial higher moisture content of guar gum coated potato chips was result of barrier properties of coating agents which prevent water loss during frying and by this mechanism water content of coated chips were higher than non-coated chips (A. D. Garmakhany *et al.*, 2008). Hence, because of the barrier properties, moisture content of the best sample increases by lower amount during storage and there was gradual increase in the moisture content of the control sample during storage period.

4.7.2 Peroxide value

The peroxide value of the sample (Control) was observed to be 1.312 at initial which reached 1.752, 2.183, 2.534 and 2.922 within 10, 20, 30 and 40 days respectively. Similarly, for sample C(Best) peroxide value was 1.191 at initial which reached 1.412, 1.652, 1.912 and 2.210 within 10, 20, 30 and 40 days respectively but the PV obtained was far below the unacceptable level of maximum 10 $MeqO_2$ /kg fat as described by DFTQC. (2022) till the last date of analysis. The rapid increase in the peroxidase value of sample control might be due to the presence of high amount of unsaturated fatty acid in chips. The increase amount of unsaturated fatty acid is prone to rancidity. The change in peroxide value of the sample C and sample G is shown in Figure. 4.7.

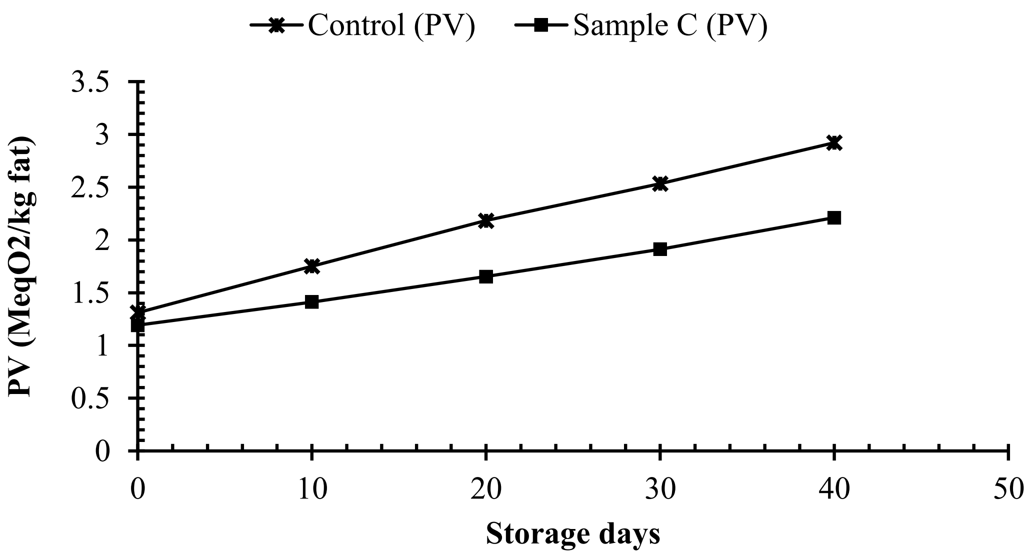

Fig. 4.7 Change in peroxide value during storage of control and best sample

Statistical analysis using a paired t-test revealed a significant difference in PV between the Control and Sample C. The average PV was 2.1406 for the Control and 1.6754 for Sample C. Variance was higher in the Control (0.4012) than in Sample C (0.1616), indicating that Sample C had a more consistent peroxide value. The t-statistic (two-tailed), confirms that there is a significant effect ($P<0.05$) of difference at 5% level of significance between the peroxide value of the two samples.

The oxidative state of frying is assessed by the measure of peroxide value (PV). Peroxide value provides a means of predicting the risk of the development of flavor rancidity. The hydrocolloid films having lower light and oxygen permeability resulted in potato chips with lower PV. The increase in PV of chips increases with the lipid oxidation in the presence of light and oxygen (Marina et al., 2009). The hydrocolloid coatings could have lowered the oxygen permeability, which resulted in potato chips with lower PV. Guar gum, being a linear polysaccharide with small chains formed by other sugars has the ability to react with in the cell wall and can be more productive as its coordinative reaction can quickly induce gel (Hua *et al.*, 2015). Nevertheless, the peroxide value less than 10 meq oxygen/ kg is the safe limit for storage of chips (Manikantan *et al.*, 2014) and it is evident that all the samples (including control) fell below this level and is deemed fit for consumption.

4.7.3 Acid Value

The acid value of control sample was observed to be 0.293 at initial which reached 0.345, 0.410, 0.47 and 0.535within 10, 20, 30, and 40 days respectively. Similarly, for sample C acid value was 0.262 at initial which reached 0.290, 0.325, 0.365, and 0.412 within 10, 20, 30, and 40 days respectively but the acid value was below the unacceptability level of 6 mg KOH/mg of oil as described by DFTQC. (2022). The change in the acid value of the sample control and sample C is shown in Figure. 4.8. The acid value of control sample was greatly increased than that of sample C. It might be due to the presence of lipase enzyme, which hydrolyses the fat present to the free fatty acid and glycerol (Oropeza, 2018). The increase in the fatty acid ultimately increases the acid value.

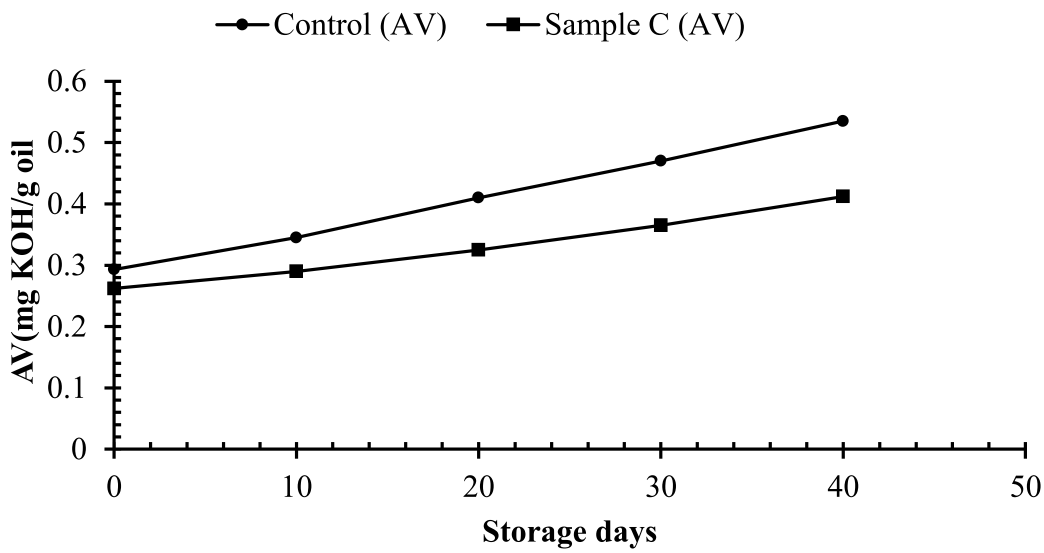

Fig. 4.8 Change in acid value during storage of control and best sample

Statistical analysis using a paired t-test revealed a significant difference between the two samples, with Sample C exhibiting a mean acid value of 0.3308 compared to 0.4106 for the Control. The variance was lower in Sample C (0.0035) than in the Control (0.0093), indicating greater stability in acid value, which suggests that the coating in Sample C effectively reduced lipid oxidation during storage. The t-statistic (two-tailed) confirmed a significant effect ($P < 0.05$) at the 5% level of significance between the acid values of the two samples. This finding aligns with studies by Hidalgo and Zamora (2017) which highlight the effectiveness of stabilization techniques in improving the oxidative stability of food products.

In general, the acid value is the indication of free fatty acid content in the product. The increment in the fatty acid of the product was found increased with storage time and depends on storage condition. Higher FFA values during frying are due to nucleophilic attack at the ester bond on triacylglycerol and the hydrolysis that happens upon removal of water from the food being fried (Manikantan *et al.*, 2014).

Oil in the chips often becomes rancid during storage and the rancidity may be caused by the conversion of oil into free acids which is reflected by the acid value or it may be caused by oxidation of fat leading to the formation of peroxides. Therefore, both acid value and peroxide value were determined. Although changes in acid value were similar to that in peroxide value, differences were greater in peroxide value. Peroxide value appears to be a fairly reliable index of the extent of oxidative deterioration of chips (Ezekiel and Rani, 2006).

Hence, from the above study, the prepared guar gum coated potato chips and non-coated potato chips were fit for consumption till the last day of analysis in terms of moisture content, peroxide value and acid value.

Part V

Conclusion and Recommendations

5.1 Conclusion

1. Potato chips were prepared by pre drying potato slices for different time and coating guar gum on different levels and storage stability of the prepared chips was studied. On the basis of the research following conclusions were drawn.
2. The moisture content, crude protein, crude fat, crude fiber, total ash content and carbohydrate of raw potato were found to be in acceptable level.
3. The acid value, peroxide value and iodine value of palm oil was found to be in acceptable level of Nepalese standard.
4. The effect of pre drying and guar gum coating on oil uptake of potato chips was studied and oil uptake was reduced to 23.02 % in 90 min 0.75% guar gum coated potato chips.
5. From sensory analysis of the product conducted on the attributes like appearance, color, taste, texture and overall acceptability, potato chips with 0.75 % guar gum coating and 60 min pre drying i.e., Sample C was rated as best in all attributes.
6. The moisture content, crude protein, crude fat, crude fiber, total ash content and carbohydrate of best sample were found to be in acceptable range. The fat content of best sample (C) was reduced by 44.34 %.
7. The moisture content, acid value and peroxide value of the best sample increased in lower rate than control, but both the samples were in acceptable range till the last day of analysis (40 days).

5.2 Recommendations

The experiment can be further continued with the following recommendations:

1. Pre drying and guar gum coating can be used for the production of low-fat products.
2. The shelf life of potato chips could further be studied.
3. Frying time and frying temperature can be varied.
4. Different packaging materials can be experimented.

Part VI

Summary

Potato is an essential crop cultivated worldwide, and potato chips are a popular processed snack. However, their high oil content poses health concerns. Coating potato slices with guar gum has been shown to reduce oil uptake during frying, improve texture, enhance overall acceptability, reduce fat rancidity risk, and extend shelf life. For the preparation, fresh potatoes were washed, peeled, and sliced uniformly at 1.5 mm thickness. The slices were pre-dried for 30, 60, or 90 minutes, then dipped in guar gum solutions of varying concentrations (0.25%, 0.5%, 0.75%, and 1%). After dipping, the slices were drained and fried in refined palm oil at 180 ± 5°C for 3 minutes. The fried chips were then cooled, drained of excess oil, packed in PP packaging, and stored at room temperature (27 ± 3°C) for shelf-life evaluation.

Proximate analysis of raw potatoes showed moisture, crude protein, crude fat, crude fiber, ash, and carbohydrate contents of 81.086%, 2.03%, 0.1%, 1.1%, 0.9%, and 18.01%, respectively. Proximate analysis of the best chips sample (0.75% guar gum coating, pre-dried for 60 minutes) showed moisture content, crude protein, crude fat, crude fiber, ash, and carbohydrate values of 2.801%, 6.025%, 25.76%, 3.81%, 2.10%, and 62.306%, respectively, compared to 2.512%, 5.815%, 46.27%, 3.015%, 2.07%, and 42.843% for the control chips respectively. The guar gum coating reduced fat content by 44.34% compared to control. Sensory evaluation favored chips pre-dried for 60 minutes and coated with 0.75% guar gum, which scored highest in appearance, texture, taste, and overall acceptability.

The shelf-life study of the best sample revealed moisture content values of 2.801%, 2.950%, 3.150%, 3.377%, and 3.610% after 0, 10, 20, 30, and 40 days, respectively. Peroxide values increased gradually from 1.191 meqv O2/kg to 2.379 meqv O2/kg, while acid values increased from 0.262 mg KOH/g to 0.428 mg KOH/g over the same period. All values remained within safe consumption limits throughout the 40-day analysis period. This study concludes that guar gum coating effectively reduces oil uptake, improves nutritional quality, and prolongs shelf life, offering a viable approach for healthier snack production.

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Appendices

Appendix-A

SENSORY ANALYSIS SCORE CARD

Name: ………………………… Date: ……………

Name of the product: guar gum coated potato chips

Dear panelist, you are provided with samples of guar gum coated potato chips. Please test the following samples of chips and check how much you prefer for each of the samples. Give the points for your degree of preferences for each parameter for each sample

Like extremely – 9	Like slightly – 6	Dislike moderately – 3
Like very much – 8	Neither like nor dislike -5	Dislike very much - 2
Like moderately – 7	Dislike slightly – 4	Dislike extremely – 1

: Judge the characteristics on the 1-9 scale as below:

Parameters	**Sample**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Appearance							
Taste							
Color							
Texture							
Overall acceptability							

Comments if any: Signature: …………

Appendix B

Table B.1 List of equipment used

Physical apparatus	
Heating arrangement	Soxhlet assembly
Thermometer	Electric balance
Kjeldahl digestion and distillation set	Muffle furnance
Titration apparatus	Hot air oven
Iodine flask	Desiccators
Blotting paper	Chopping board and knife
Slicer	Daily routine glassware

Table B.2 List of chemicals used

Chemicals	
Sodium hydroxide	Potassium Iodide
Sodium thiosulphate	Boric acid
Ethanol	Acetic acid
Phenolphthalein	Chloroform
Petroleum ether	Catalyst mixture
Potassium metabisulphite	Sulphuric acid

Appendix C

ANOVA results of sensory analysis

Table C.1 ANOVA (no interaction) for appearance of guar gum coated potato chips

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Chips type	6	56.1587	9.3598	37.05	<.001
Panelist	8	3.6508	0.4563	1.81	0.099
Residual	48	12.1270	0.2526		
Total	62	71.9365			

Table C.2 ANOVA (no interaction) for color of guar gum coated potato chips

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Chips type	6	52.6667	8.7778	26.98	<.001
Panelist	8	3.7143	0.4643	1.43	0.210
Residual	48	15.6190	0.3254		
Total	62	72.00			

Table C.3 ANOVA (no interaction) for taste of guar gum coated potato chips

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Chips type	6	41.2063	6.8677	21.86	<.001
Panelist	8	3.1429	0.3929	1.25	0.291
Residual	48	15.0794	0.3142		
Total	62	59.4286			

Table C.4 ANOVA (no interaction) for texture of guar gum coated potato chips

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Chips type	6	105.5238	17.5873	130.35	<.001
Panelist	8	0.8571	0.1071	0.79	0.610
Residual	48	6.4762	0.1349		
Total	62	112.8571			

Table C.5 ANOVA (no interaction) for overall acceptability of guar gum coated potato chips

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Chips type	6	53.6508	8.9418	59.56	<.001
Panelist	8	0.7937	0.0992	0.66	0.723
Residual	48	7.2063	0.1501		
Total	62	61.6508			

Appendix D

Table D.1 t-test (two-sample assuming unequal variance) for moisture of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	2.512	2.801
Variance	0.000183	0.000273
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-23.44099535	
P(T<=t) one-tail	9.816715	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.000019	
t Critical two-tail	2.776445105	

Table D.2 t-test (two-sample assuming unequal variance) for protein of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	5.815	6.025
Variance	0.002275	0.003225
Observations	3	3
Hypothesized Mean Difference	0	

df	4
t Stat	-4.904543
P(T<=t) one-tail	0.004008
t Critical one-tail	2.131847
P(T<=t) two-tail	0.008018
t Critical two-tail	2.776445

Table D.3 t-test (two-sample assuming unequal variance) for fat of the best sample (sample G) with control (sample C).

	Sample G (Control)	Sample C (Best)
Mean	46.254	25.76
Variance	0.001429	0.000916
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	732.956174	
P(T<=t) one-tail	0.0000000000104	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.000000000020789	
t Critical two-tail	2.776445	

Table D.4 t-test (two-sample assuming unequal variance) for fiber of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	3.015	3.81
Variance	0.002775	0.002925
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-18.238551	
P(T<=t) one-tail	0.000026	
t Critical one-tail	2.131846	
P(T<=t) two-tail	0.000053	
t Critical two-tail	2.776445	

Table D.5 t-test (two-sample assuming unequal variance) for ash of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	2.058667	2.099333
Variance	0.000182	0.000226
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-3.48429	
P(T<=t) one-tail	0.012627	

t Critical one-tail	2.131847
P(T<=t) two-tail	0.025253
t Critical two-tail	2.776445

Table D.6 t-test (two-sample assuming unequal variance) for carbohydrate of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	40.38833333	61.50433
Variance	0.009402333	0.011002
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-256.039829	
P(T<=t) one-tail	0.000000000697986	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.0000000014	
t Critical two-tail	2.776445105	

Table D.7 t-Test (Paired Two Sample for means) for change in moisture content during storage of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	2.9718	3.1744
Variance	0.1732142	0 .1073703
Observations	5	5
Pearson correlation	0.999581252	
Hypothesized Mean Difference	0	
df	4	
t Stat	-5.08112641	
P(T<=t) one-tail	0.003537578	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.007075156	
t Critical two-tail	2.776445105	

Table D.8 t-Test (Paired Two Sample for means) for change in peroxide value during storage of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	2.1406	1.6754
Variance	0.4011838	0.1615868
Observations	5	5
Pearson correlation	0.995204156	
Hypothesized Mean Difference	0	

df	4
t Stat	4.395974102
P(T<=t) one-tail	0.005863946
t Critical one-tail	2.131846786
P(T<=t) two-tail	0.011727891
t Critical two-tail	2.776445105

Table D.9 t-Test (Paired Two Sample for means) for change in acid value during storage of the best sample (sample C) with control (sample G).

	Sample G (Control)	Sample C (Best)
Mean	0.4106	0.3308
Variance	0.0092843	0.0035487
Observations	5	5
Pearson correlation	0.997549679	
Hypothesized Mean Difference	0	
df	4	
t Stat	4.801308466	
P(T<=t) one-tail	0.004319951	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.008639902	
t Critical two-tail	2.776445105	

Color Plates

P.1 Potato slicer

P.2 Soxhlet apparatus

P.3 sliced potato

P.4 Potato chips